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Nutrient and Carbon Dynamics in the Chesapeake Bay Outflow Plume and Their Effect on the Coastal Ocean Environment

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NUTRIENT AND CARBON DYNAMICS IN THE CHESAPEAKE BAY OUTFLOW PLUME AND THEIR EFFECT ON THE COASTAL OCEAN ENVIRONMENT

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ABSTRACT

NUTRIENT AND CARBON DYNAMICS IN THE CHESAPEAKE BAY OUTFLOW PLUME AND THEIR EFFECT ON THE COASTAL OCEAN ENVIRONMENT

Katherine C. Filippino
Old Dominion University, 2008
Director: Dr. Margaret Mulholland

Seasonally resolved nutrient and carbon fluxes from estuaries to the coastal ocean are poorly constrained. Nutrient and carbon cycling in highly productive regions like the Chesapeake Bay outflow plume and surrounding coastal environments greatly affect our global understanding of carbon cycling. The overall questions for the research described in this dissertation stem from the need to close global carbon budgets, and obtain a fundamental understanding of nutrient dynamics in a coastal region heavily influenced by seasonality and human impacts.

Within the framework of physical characteristics of the outflow plume and through the characterization of nutrient concentrations, primary productivity rates, and the uptake of nitrogen using stable isotopes, I identified three different plume types that differentially provided nutrients and created conditions either suitable or unsuitable for primary productivity in the coastal zone. A jet-like plume, where there were winds consistently from the north accompanied by high freshwater flow from the Bay, delivered high amounts of chlorophyll from the Bay. In contrast, two types of diffusive plumes occurred when winds came from the south accompanied with low freshwater discharge and were either influenced by estuarine or oceanic processes. The diffusive-estuarine plume delivered dissolved nutrients creating conditions suitable for high primary productivity rates in the coastal zone while the diffusive-oceanic plume generally had low primary productivity and nitrogen uptake rates.

A secondary study compared and contrasted hydrography, nutrient availability, primary productivity rates and nitrogen uptake rates in three distinct regions of the Mid-Atlantic Bight: the plume regions influenced by the Delaware and Chesapeake Bays, the mid-shelf region between the Delaware and Chesapeake Bays influenced by both coastal and oceanic processes, and the southern shelf region below the Chesapeake Bay influenced by the Gulf Stream. Areal rates of carbon uptake were not significantly different among regions, and were higher than most published values of annual areal rates for the Mid-Atlantic bight. Annual areal nitrogen uptake rates were also calculated, providing carbon to nitrogen uptake ratios which were lower than the canonical Redfield ratio. These findings have implications regarding modeled estimates of carbon uptake based on nitrogen uptake and vice versa.

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CHAPTER I

THE COASTAL ZONE

INTRODUCTION

Estuaries are an important interface between the terrestrial and oceanic environment with bay mouths and outflow plumes acting as mixing zones to provide nutrients, dissolved inorganic carbon (DIC) for primary productivity and dissolved organic carbon (DOC) for heterotrophic production in the coastal zone. Although research has been undertaken to understand the sources, cycling, and biogeochemistry of nutrients within the main-stem of estuaries, nutrient import and export studies through the estuarine-oceanic interface are rare. Nutrients that enter most aquatic systems are processed within estuaries as they are transported to the coastal ocean. In this dissertation, I will examine the delivery of nutrients to the coastal zone via the estuarine plume of the Chesapeake Bay versus oceanic sources with respect to physical parameters using temperature, salinity, and terrestrial freshwater inputs to characterize different physical regimes. By approaching nutrient dynamics in a physical context, I will address how different physical regimes affect nitrogen uptake and primary productivity in the coastal zone surrounding the mouth of the Chesapeake Bay. I also will compare these findings with N uptake and primary productivity to the north, south, and east of the plume region in order to assess the spatial extent of the Bay's effect on the coastal zone.

BACKGROUND

The quality and quantity of terrestrial nutrient inputs heavily impacts estuarine processes, fueling primary productivity, microbial activity, fish production and fisheries

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This dissertation follows the journal style of Limnology and Oceanography.

yield. Although estuarine material is altered by internal biogeochemical cycling and recycling, estuaries are ultimately sources of nutrients and C to the coastal ocean. Currently, Chesapeake Bay tributaries and part of the main stem suffer from eutrophication. In semi-enclosed water bodies and coastal bays, too much nitrogen (N) and phosphorous (P) leads to the development of excess biomass which degrades the overall health and well-being of marine life (Fisher et al. 1988; Harding and Perry 1997). Both point sources (e.g. industry and wastewater treatment plants) and non-point sources (e.g. urban and agricultural runoff, and atmospheric deposition) of nutrient pollution contribute to the eutrophication of the Bay (Kemp et al. 2005). However, non-point source pollution is the dominant source of nutrients to the Bay (Kemp et al. 2005).

The northeast coast of the United States is considered to be the most populated coastal region in the U.S., according to a recent NOAA coastal population trends report (Crossett et al. 2004). As of 2003, 77% of the northeast region and 37% of the southeast region reside on the coast (Crossett et al. 2004). An increase in population translates to more development, fewer buffer zones, and even more nutrient runoff into the Bay and into the coastal ocean. Population increases correlate directly to total N (TN) loads in coastal zones (Howarth et al. 1996). If this trend continues, eutrophication-induced anoxia will only increase, further affecting the processing of nutrients within the Bay and the coastal ocean beyond the mouth of the Bay.

Nitrogen has a complicated cycle in aquatic systems (Fig. 1.1) and is thought to limit production in a variety of coastal regions including the MAB (Ryther and Dunstan 1971). The amount of N introduced into coastal systems, particularly to the North Atlantic, has increased dramatically over the years, and can be directly related to population growth (Howarth et al. 1996; Howarth et al. 2002). Anthropogenic sources of N to the coastal zone along the U.S. eastern seaboard, in order of decreasing magnitude are: 1) agricultural run-off, from both fertilizers and N fixation in soils, 2) atmospheric deposition of NO_x from fossil-fuel combustion, 3) point sources from industrial and wastewater treatment plants (Howarth et al. 2002). Sinks of N in the coastal zone are denitrification and storage within either terrestrial, estuarine, or coastal sediments (Howarth et al. 2002). N is an essential nutrient for growth and the amount and form of dissolved N are important drivers for determining the dominant algal species (Mulholland and Lomas 2008). Too much dissolved inorganic N (DIN) can cause excessive algal growth and even algal blooms. Research has shown that in addition to DIN, dissolved organic N (DON) can be important in fueling harmful algal blooms (Paerl 1988; Nixon 1995; Glibert et al. 2001; Mulholland et al. 2004). In coastal systems, ‘new’ or allochthonous N (Eppley and Peterson 1979) can include diverse forms of N including nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), urea, and other DON (Paerl 1997). Coastal upwelling can also introduce NO_3^- from deep oceanic sources, and water column and sediment N_2 fixation can supply reactive N to the surface water (Boynton et al. 1995; Paerl 1997). N is also recycled within the water column and sediments, via microbial processes that produce NO_3^-, NO_2^-, NH_4^+, and DON that is available for autotrophs and heterotrophs (Fig. 1.1).

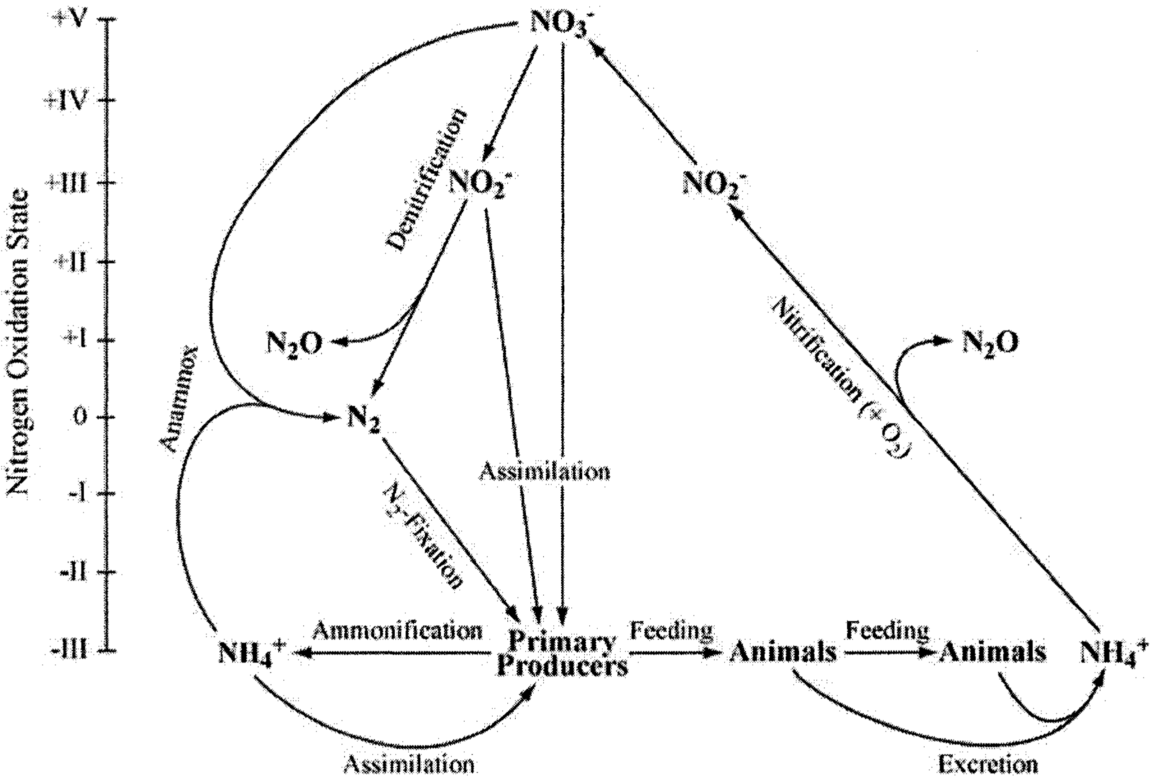

Fig. 1.1. Schematic diagram of the N cycle. N oxidation states are shown on the vertical axis, and major biological transformations between compounds and organisms are shown with arrows. Nitrification, mediated by bacteria, shows ammonia oxidation: $NH_3 + 1\frac{1}{2} O_2 \rightarrow NO_2^- + H^+ + H_2O$ and nitrite oxidation: $NO_2^- + 1\frac{1}{2} O_2 \rightarrow NO_3^-$. Denitrification is mediated by bacteria with the following chemical equation: $NO_3^- + 6H^+ + 5e^- \rightarrow \frac{1}{2}N_2 + 3H_2O$. Nitrogen fixation is performed by cyanobacteria, bacteria and archaea: $N_2 + 8H^+ + 8e^- + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16P_i$ (biological). Assimilation of inorganic N is performed by phytoplankton. Production/reduction of N_2O is dependent on concentrations of O_2, NO_2^-, etc. Anaerobic ammonium oxidation (Anammox) is also shown (Montoya 2008).

Total annual nutrient loads to coastal systems are highly dependent upon seasonal discharge events (Boynton et al. 1995). In the eastern coastal U.S., nutrient inputs are tied to freshwater discharge. During spring when precipitation is typically higher, there is high freshwater flow entering the Bay and coasts, carrying high concentrations of new nutrients (Malone et al. 1988). In contrast, during summer, when there is less rainfall there is lower freshwater flow into the Bay and therefore lower nutrient delivery to the Bay and coastal waters, but at this time nutrient recycling rates are high (Malone et al. 1988). Nutrient limitation is also tied to the seasonal freshwater flow cycle. Algal growth in the Bay can be limited by N, P or silicon (Si) or co-limitation can occur by two or more of these nutrients (Fisher et al. 1999). In the lower Bay, N and P are thought to co-limit algal growth in the winter and spring, followed by a small period of time where P-limitation may occur. The lower Bay is generally N-limited during summer and fall mainly due to recycling processes which regenerate P faster than N and due to the low N to P ratio in the oceanic influenced end-member (Fisher et al. 1992; Fisher et al. 1999; Kemp et al. 2005). Variations in the pattern of nutrient limitation may also occur along the mouth of the Bay, where there exists a north-south salinity gradient due to bathymetry and estuarine circulation (Valle-Levinson et al. 1998; Whitford 1999). There is higher freshwater discharge along the western side of the Bay and at the southern entrance to the Bay mouth and therefore potential for higher nutrient delivery at these boundaries (Valle-Levinson et al. 1998; Whitford 1999).

The seasonal shift in nutrient availability in the lower Bay and Bay mouth may also extend into the coastal waters as nutrients and materials are delivered through the Bay mouth. The flux of N and P into and out of the Bay at the estuarine-coastal interface is important for determining nutrient budgets and primary productivity but difficult to estimate. Although flow rates can be estimated, nutrient fluxes over even a diurnal cycle are difficult to estimate in a region where both biological and physical interactions occur on short timescales.

In addition to freshwater flow, tidal fluctuation at the estuarine-coastal interface is important for nutrient availability and algal growth. Mixing and salinity gradients within the water column are affected by the tidal cycle, and that can either facilitate or hinder nutrient delivery to coastal waters from estuarine and oceanic sources (Guo and Valle-Levinson 2007). For example, tidal currents outside of the Bay mouth can weaken stratification by increasing mixing (Guo and Valle-Levinson 2007) and therefore create a well-mixed physical regime bringing nutrients to surface waters where it is optimal for phytoplankton growth. However, increased mixing can result in high turbidity and low light penetration, which is not optimal for growth (Pennock and Sharp 1994).

Coupled with large inputs of nutrients via freshwater discharge to the Chesapeake Bay and its tributaries are seasonal phytoplankton blooms and microbial activity that biologically influence nutrient cycling *en route* to the coastal ocean. Complex nutrient biogeochemistry tied to biological processes confounds our ability to extrapolate C productivity and C fluxes from within the estuary to the coastal ocean. Also, current global ocean and atmospheric C cycle models are poorly constrained in the coastal ocean environment despite the observations that these are areas where C (and nutrient) cycling is intense (Hoffman et al. 2008). Further, increasing anthropogenic impacts, such as increased carbon dioxide (CO_2) emissions and increased atmospheric temperatures, are affecting CO_2 exchange between the ocean and atmosphere. Although the global continental shelf (the shallow (<200 m) area surrounding land margins) represents only a small fraction of the ocean's surface area (< 10%), these areas play a large role in global C cycling by accounting for more than 21% of total oceanic productivity (Gattuso et al. 1998; Jahnke 2007). They are also areas where biology and vertical water column movements interact to affect C exchange with the atmosphere (Gattuso et al. 1998; Jahnke 2007).

The two largest biologically reactive C pools in the ocean are the DIC pool and the DOC pool. DIC fuels primary productivity via photosynthetic C fixation and its concentrations are also controlled by air-sea exchange due to temperature-dependent solubility (Sarmiento and Gruber 2006). In contrast, the DOC pool is a complex mixture of components released from autotrophs, heterotrophs, inputs from rivers, and fuels heterotrophic microbial growth. The Amazon River basin is just one example of a well-studied coastal system influenced by large riverine discharge, and although vastly different from the Chesapeake Bay system, extensive research conducted there provides insights regarding C dynamics in coastal systems. The Amazon River is responsible for 20% of the world's river discharge and the export of total organic carbon (TOC) and DIC from the entire basin to the ocean has been estimated at 3×10^{12} mol C y^{-1} each (Richey et al. 1980; Degens et al. 1990; Richey et al. 2002). This estimate is only 5 - 10% of global TOC and 10% of global DIC entering coastal zones, but is important regarding the ability of the oceans to take up anthropogenic atmospheric CO_2, as the main function of riverine discharge in the global C budget is the export of C to the ocean (Degens et al. 1990; Richey et al. 2002). Without budgeting for riverine TOC and DIC export in C cycle models, the estimation for the oceans ability to take up anthropogenic CO_2 may be overestimated (Sarmiento and Sundquist 1992).

In addition to bulk C export, coastal C research is focused on obtaining estimates of chromophoric dissolved organic matter (CDOM) and DOC concentrations in the MAB via satellite remote sensing to better understand net ecosystem productivity (Del Vecchio and Blough 2004; Mannino et al. 2008). However, these models are in need of continued field campaigns to aid in algorithm validation and may not predict coastal regional productivity with much certainty at the coastal/land interface (Mannino et al. 2008). The difficulties surrounding remote sensing and algorithm validation are due to discrepancies between the timing of field observations and satellite observations, and the complexity of the optical properties within coastal water columns (Mannino et al. 2008). Therefore further *in situ* examination of N and C productivity in many coastal systems, including the Chesapeake Bay outlflow plume is necessary (Werdell and Bailey 2005; Mannino et al. 2008).

We know from multiple biogeochemical process studies conducted in regions affected by plumes (see Table 1.1 and references therein) that estuarine and riverine plumes can be areas of high productivity and can exert profound effects on the coastal ocean environment. Despite their high productivity, coastal zones are under-sampled in regards to other environments (Richardson and Poloczanska 2008). Further, most previous studies of coastal biogeochemistry represent only one or two seasons (Table 1.1). In a recent Intergovernmental Panel on Climate Change (IPCC) report, only 30 data series were included in their evaluation of climate change in the marine (both biological and physical) environment, due to the lack of time series measurements (Richardson and Poloczanska 2008). Unlike the Chesapeake Bay proper, the Chesapeake Bay plume has not been intensely studied, specifically with respect to the very dynamic N and C cycles.

Other river plumes that are vastly different from the Chesapeake Bay plume, such as the Amazon and Mississippi Rivers, have been sites for more extensive biogeochemical and physical studies (Table 1.1). As the largest estuarine system in North America, and a coastal plain estuary discharging into the MAB, it is important to investigate the impact that the Chesapeake Bay system has on the biogeochemical cycling in the highly productive MAB, and how climatological factors influence the penetration of the plume into coastal waters.

Table 1.1. Summary of downstream biogeochemical effects of estuaries on coastal environments.

Study Area	Focus of Study	References
Chesapeake Bay outflow plume	Microbial-phytoplankton relationships	(Malone and Ducklow 1990)
	DFAA cycling	(Fuhrman 1990)
	Seasonal and diel N dynamics	(Glibert and Garside 1992; Glibert and Capone 1993)
	Larval transport	(Epifanio and Garvine 2001)
Amazon River plume	Organic C oxidation, transformation and delivery	(Richey et al. 1980)
	Biological uptake of silica	(Demaster et al. 1983)
	Discharge with respect to climate variability	(Richey et al. 1989)
	Primary productivity and biomass	(Smith and Demaster 1996)
	Biogeochemical processes of C, N, and Si	(Demaster et al. 1996)
	CO_2 flux	(Richey et al. 2002)
	C sink	(Cooley and Yager 2006)
	Cyanobacterial abundance	(Foster et al. 2007)
Mississippi River plume and Gulf of Mexico	Chemical survey including: H^+, Ca^+, inorg. P, C, and N, O_2, CH_4	(Fox et al. 1987)
	N, DON and pigments in Miss. R. plume	(Hitchcock and Whitledge 1992; López-Veneroni and Cifuentes 1994)
	N cycling and regeneration in Miss. R. plume	(Gardner et al. 1997)
	Nutrients, light and mixing in Miss. R. plume	(Lohrenz et al. 1999)
	NH_4^+ recycling and primary productivity	(Wawrik et al. 2004)
	Organic carbon, nutrients, and pigments in surface waters and sediments	(Wysocki et al. 2006)
	P-limitation and co-nutrient limitation	(Sylvan et al. 2007)
Hudson River plume	Phytoplankton size fractions-production and fate	(Malone 1977; Malone and Chervin 1979)
	Bacterial dynamics	(Ducklow and Kirchman 1983)
	Carbon cycling	(Taylor et al. 2003)
	Whole ecosystem dynamics	(Morgan 2006)

Table 1.1. Continued.

Study Area	Focus of Study	References
Adriatic Sea and Po River plume	Discharge effects on phytoplankton dynamics	(Revelante et al. 1985)
	Phytoplankton blooms and discharge	(Penna et al. 2004)
	Modeling nutrient discharge and hydrography	(Spillman et al. 2007)
Yangtze River and Pearl River Estuary into the East China Sea	Chemical hydrography, nutrients and Chl *a*	(Gong et al. 1996)
	Nitrate inputs	(Lee Chen et al. 1999)
	Historical eutrophication	(Wang 2006)
	Nutrient limitation and primary productivity	(Yin et al. 2000)
	Nutrient limitation shifts; wind effects on phytoplankton blooms	(Yin et al. 2001; Yin et al. 2004)

STUDY SITE

The Chesapeake Bay plume is a buoyant jet that results from subtidal outflow entering the shelf region, turning anticyclonically, and being trapped against the coast due to the earth's rotation (Valle-Levinson and Lwiza 1997; Valle-Levinson et al. 1998) (Fig. 1.2). The circulation pattern at the mouth of the Chesapeake Bay, as it enters the coastal zone, has been described as a two-way exchange with seawater flowing in at depth at the northern side and lower salinity water flowing out at the surface primarily along the south side of the mouth of the Bay (Valle-Levinson et al. 1998). This pattern is a combination of circulation due to density gradients, wind-induced flow, and bathymetry (Valle-Levinson and Lwiza 1997; Valle-Levinson et al. 1998; Valle-Levinson et al. 2001). In addition, tidal currents are important when observing vertical and horizontal plume structure, as tides create a plume that can extend all the way to the bottom of the water column and tides tend to inhibit the expansion of the plume northward (Guo and Valle-Levinson 2007).

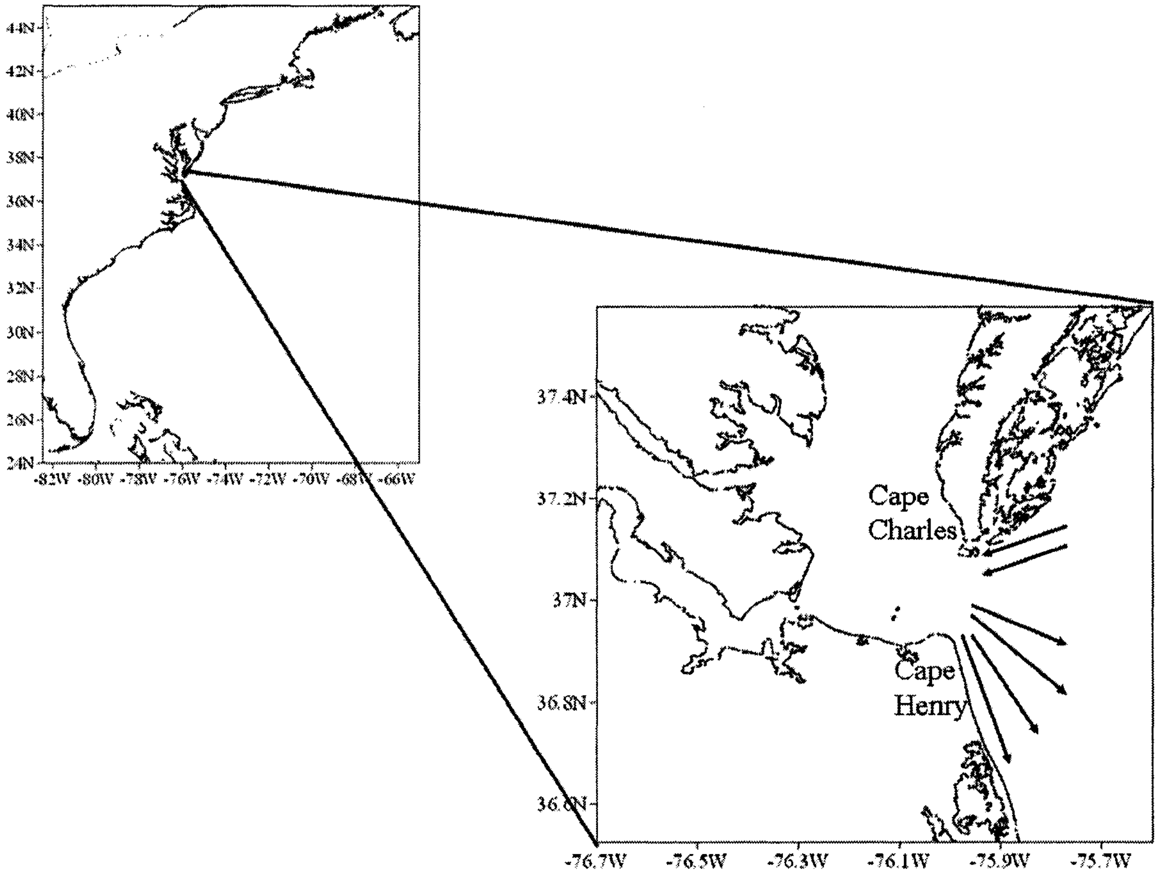

Fig.1.2. Chesapeake Bay outflow plume and coastal zone. Arrows are indicative of the general circulation pattern with oceanic waters entering at depth on the north end of the Bay mouth, and estuarine waters exiting at the surface at the south end of the Bay mouth.

Wind stress and freshwater flow play major roles in the extent of the low salinity waters as they move through the Bay mouth and out into the coastal Atlantic (Johnson et al. 2001; Valle-Levinson et al. 2001). Just south of the Bay mouth, alongshore winds from the north, common between late summer and spring, can result in coastal downwelling which serves to strengthen the outflow jet and confine the southward flow of water near the coast to the south of the Bay mouth (Valle-Levinson et al. 1998; Johnson et al. 2001). Under this condition, nutrients and C inputs to the coastal ocean from the Chesapeake Bay are restricted to a narrow band along the southern coast of VA. In the summer, weaker winds blow from the south resulting in offshore Ekman transport and broadening of the plume, potentially distributing material containing nutrients and C further offshore, and causing coastal upwelling near the Bay mouth (Johnson et al. 2001). In addition to wind-driven seasonal upwelling and downwelling, evidence has shown that fronts can form along the Virginia coast, similar to those occurring in the Delaware Bay (Sanders and Garvine 1996; Marmorino et al. 2000). These fronts typically occur near Cape Henry and are more typical during high tide and under high flow conditions (e.g., spring). During these events, denser water is trapped along the coast and can downwell. Associated dissolved and particulate material with the downwelled surface water can then become entrained in the northward flow potentially moving back into the estuary (Marmorino et al. 2000). The complex circulation that characterizes coastal environments is influenced by and modifies the effects of the estuary on coastal nutrient and C dynamics.

RESEARCH QUESTIONS

In order to examine the fate and transport of N and C through the Bay mouth and in the plume, the following research questions were addressed: ***What role does seasonal variability of freshwater outflow and meteorology play in nutrient and carbon dynamics and primary productivity in a coastal region and how does freshwater flow and meteorology affect the exchange of carbon and nutrients at the coastal interface? How does primary productivity and nutrient and C cycling along the north-south axis of the Chesapeake Bay outflow plume (when the plume is a distinct jet running from***

north to south) compare to the west-east axis (when the plume is more dispersed in a west to east direction)?

In Chapter 2, these questions are addressed via ship-based studies of bulk water column measurements and process studies (i.e. stable isotope tracer experiments) examining biological activity during low and high freshwater discharge events and at stations both inside and outside of the Chesapeake Bay outflow plume's influence. Preliminary research along a Chesapeake Bay mouth transect showed seasonal trends in nutrient concentrations (Fig. 1.3; Filippino unpublished data). Overall, 2003 and 2004 were considered wet years, based on USGS stream flow data, where wet years were defined as flow greater than the 75th percentile of annual river flow since the beginning of data collection in 1937 (http://md.water.usgs.gov/monthly/bay.html#wymean). Monthly and seasonal river discharge into the Chesapeake Bay from the major tributaries, including the James River, was highest in the spring of 2003. Chlorophyll *a* (Chl *a*) concentrations increased following the large freshwater discharge in the spring, and decreased as flow decreased during summer of 2003 (Fig. 1.3A). However, there were no significant relationships ($p > 0.05$) between nutrient and Chl *a* concentrations and freshwater flow from the James River in either 2003 or 2004 (Figs. 1.3A - D). These data suggest that seasonality and freshwater flow alone are not good predictors of changes in nutrient and Chl *a* concentrations, as localized and large-scale freshwater flow events can alter nutrient concentrations significantly during multiple seasons. Further, biological activity along the length of the estuary and the hydrodynamics of the outflow plume and surrounding coastal waters can complicate the interpretation of bulk water column measurements.

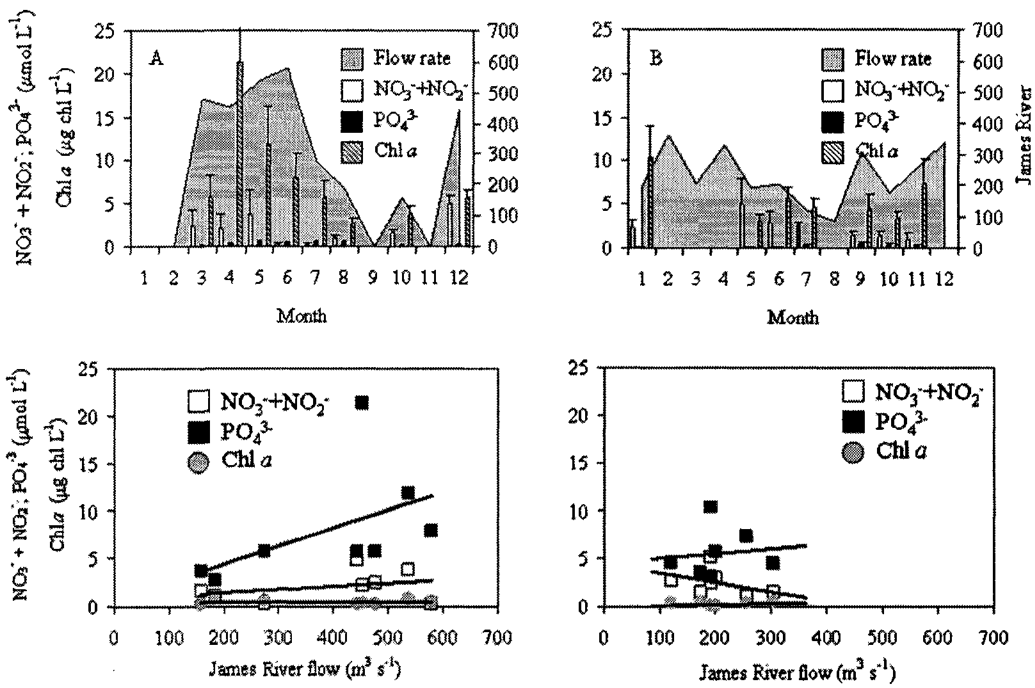

Fig. 1.3. Monthly nutrient concentrations and freshwater flow from the James River at the mouth of the Chesapeake Bay during 2003 and 2004. The top panels show average NO_3^- + NO_2^-, PO_4^{3-}, and Chl *a* concentrations (µmol L^{-1} and µg chl L^{-1}; bars) and monthly averaged freshwater flow from the James River (m^3 s^{-1}; shaded area) at the Bay mouth for 2003 (A) and 2004 (B), error bars are standard deviations for surface and near-bottom depths at four stations across the Bay mouth. The bottom panels show linear regressions between James River discharge and NO_3^- + NO_2^- (2003: R = 0.33; 2004: R = 0.41), PO_4^{3-} (2003: R = 0.50; 2004: R = 0.10), and Chl *a* (2003: R = 0.10; 2004: R = 0.30) in 2003 (C) and 2004 (D) (Filippino unpublished data).

In order to assess the productivity in the coastal ocean in the context of coupled N and C cycling, Chapter 3 describes the influence and importance of the outflow plume to N and C dynamics in the receiving waters and the MAB as a whole. Specifically, the following question was examined: ***What effect do terrestrial influences have on the quality and quantity of nutrients and carbon available for uptake in the coastal region?*** Similar to the study of the plume region, process cruises were conducted examining on-shore versus off-shore N and C dynamics in the MAB. This research was aimed at comparing current N and C budgets in the MAB with past research and place current productivity estimates in a historical and hydrographic context.

Chapter 4 provides a discussion of the research results described in Chapters 2 and 3. The goal in Chapter 4 is to synthesize this research in the context of our current understanding of N and C cycling in coastal systems, regional models of productivity, and to highlight future directions.

CHAPTER II

NUTRIENT DYNAMICS AND PRIMARY PRODUCTIVITY IN THE CHESAPEAKE BAY OUTFLOW PLUME; 2005 - 2007

INTRODUCTION

Estuaries are an important and productive interface between the terrestrial and oceanic environments. The bulk of terrestrial material transported to the coastal ocean is delivered through rivers and estuaries that also act as reactors, transforming material and nutrients *en route*. Both the quantity and quality of nutrients delivered to the coastal zone depend on their residence time in the estuary and reactions within the estuary.

Relationships between nutrient loading from the watershed and subsequent export to the coastal ocean are complex. Evaluations of the total nutrient load, particularly N, to the Chesapeake Bay have been undertaken, and present and past literature has shown that N inputs to the Bay are increasing over time leading to eutrophication and overall Bay degradation (Boynton et al. 1995; Kemp et al. 2005). There is typically high N demand in the mesohaline section of the Bay during the summer and low demand in winter (Baird and Ulanowicz 1989; Baird et al. 1995). This is primarily due to the large supply of nutrients during the spring that support a spring bloom and recycling of algal N during summer (Baird et al. 1995). Phytoplankton growth was found to be P-limited in the lower salinity regions of the Bay and N-limited in the higher salinity regions (Fisher et al. 1999). Temporally, phytoplankton growth is typically limited by P in the spring followed by N-limitation in the summer (Fisher et al. 1999).

Large-scale budgets of N and C in the coastal MAB have been estimated and estuarine and riverine discharge represents between 10 – 30 % of total N inputs to the western North Atlantic continental shelf (Nixon et al. 1996; Verity et al. 2002; Fennel et al. 2006). However, studies examining total N inputs to the coastal ocean from the Chesapeake Bay and the impact of this estuary on the mid-Atlantic shelf are scarce (Malone and Ducklow 1990; Glibert et al. 1991; Acker et al. 2005). Of the few studies conducted in the Chesapeake Bay plume in the late 1980's, it was found that turnover of particulate organic C (POC) and release of DON have been shown to increase with temperature due to an increase in the abundance of bacterioplankton relative to phytoplankton (Malone and Ducklow 1990; Glibert et al. 1991). Also, seasonality was observed in N uptake, with higher uptake rates observed in the spring and a shift from inorganic to organic N uptake from spring to summer (Glibert et al. 1991). More recently, satellite remote sensing has been utilized to show that high turbidity, nutrients, and Chl *a* are associated with high freshwater flow (Acker et al. 2005). However, no specific studies relating to N uptake and primary productivity within the plume have been conducted since the 1980's, and understanding the relationships between productivity and N cycling are crucial for determining how the coastal ocean, impacted by the Chesapeake Bay at present, will respond to various climate change scenarios (Gruber and Galloway 2008).

Estuarine and riverine plumes act as mixing zones where nutrients enter the coastal zone and potentially fuel coastal productivity. The Chesapeake Bay system is the largest estuary in North America and its influence on nutrient cycling and primary productivity has a potentially large impact on the coastal ocean (Boynton et al. 1995; Nixon et al. 1996). Productivity in the mid-Atlantic coastal zone is thought to be limited primarily by N (Dugdale 1967; Ryther and Dunstan 1971; Nixon et al. 1986) although such limitation may be alleviated due to anthropogenic increases in N, thus increasing primary productivity (Duce et al. 2008; Galloway et al. 2008). In contrast to the coastal zone, the Chesapeake Bay is considered eutrophic and its outflow plume discharges into this otherwise nutrient-depleted coastal area. While many processes influence N dynamics and C productivity in the coastal ocean, seasonally variable nutrient inputs through estuarine and riverine plumes can play a large role in coastal systems where they discharge (Nixon et al. 1996). The timing and location of high and low flow events, the residence time of material in the Bay with respect to timescales of biogeochemical processing, the prevailing oceanographic conditions, and seasonally variable ecosystem dynamics may be important for determining the impacts of plume-derived nutrients on primary productivity in the coastal zone. Because of tidal and other physical influences, the two end members do not exhibit simple steady state mixing and therefore the flux rates of available nutrients at the interface between estuarine and oceanic systems are poorly understood (Malone and Ducklow 1990).

The location and strength of the plume can determine the extent of its effect on N and C cycling in the coastal waters, e.g., where and how much primary productivity occurs in the adjacent coastal zone versus further offshore. Typically, during high to moderate flow (e.g., in the spring months), material passing through the Bay mouth into the coastal ocean remains entrained in a plume or jet that extends from the Bay mouth out into the Atlantic Ocean. Prior research has shown that the Chesapeake Bay outflow plume can extend 10 - 100 km seaward during high flow periods, particularly in the winter and spring months when freshwater discharge is often high (Boicourt et al. 1987; Valle-Levinson et al. 1998; Valle-Levinson et al. 2001). In contrast, during low flow periods (e.g., in the summer months), the circulation pattern of the plume can be confined to an area near the mouth of the Bay (Valle-Levinson et al. 1998; Valle-Levinson et al. 2001). However, hurricanes and intense precipitation events during otherwise low flow periods can have dramatic effects, providing larger total N loads and resulting in long-term ecosystem changes (Paerl et al. 2001).

While it is tempting to consider freshwater discharge alone, the direction, intensity and location of the estuarine plume is a result of the combination of many physical forces (Valle-Levinson et al. 2001) including prevailing wind direction and speed, the strength of the coastal current, bathymetry, and tidal currents (Valle-Levinson et al. 1998; Guo and Valle-Levinson 2007). For example, near the Chesapeake Bay mouth and its plume, the dominant wind direction can result in both upwelling and downwelling-favorable conditions and these in turn affect the impact of the plume on the coastal system (Rennie et al. 1999; Johnson et al. 2001). Downwelling-favorable conditions can result in a deep and narrow plume, while upwelling favorable conditions can result in a shallow and wide plume. If upwelling favorable winds persist, this can result in the detachment of the plume, moving and dispersing it further offshore (Rennie et al. 1999).

While there is a general understanding of how the physical location of the estuarine plume varies in space and time (Valle-Levinson et al. 1998; Valle-Levinson et al. 2001; Guo and Valle-Levinson 2007), these assessments lack a biogeochemical framework to link spatial and temporal plume dynamics with nutrient cycling and primary production. For example, under conditions of high flow and short residence time, one might expect more dissolved and particulate material to move through the estuary less altered before it is exported to the coastal ocean, resulting in a higher availability of inorganic nutrients compared to organic nutrients, fueling autotrophic productivity. In contrast, during low flow periods when residence times in the estuary are longer, recycling processes may dominate resulting in delivery of highly altered nutrients (primarily in organic form) to the coastal ocean, fueling heterotrophy. Elucidating the nutrient variability (e.g. inorganic versus organic) and subsequent uptake and transformation into primary production would provide a better understanding of the processes occurring. Therefore, quantifying nutrient concentrations and uptake rates of inorganic and organic N sources in addition to estimating primary productivity in the context of different hydrographic regimes will allow for a broader understanding of the effect the terrestrial nutrients from the Bay have on the coastal region. Estimates of N uptake and primary productivity have been employed in numerous studies using ^{15}N and ^{13}C (or ^{14}C) tracers (Harrison 1983; Dugdale and Wilkerson 1986; Lipschultz 2008) and can provide a processed-based evaluation of the biogeochemistry of a particular system, like the Chesapeake Bay outflow plume (Lipschultz 2008).

Given forecasted changes in the dominant physical forces likely to result from climate change (e.g., sea level rise, temperature increase, and increased freshwater flow etc.), it is particularly important to understand the current range of expected values and the range of variability in biological processes under present day conditions (Nicholls et al. 2007). It is the intent of this research, therefore, to provide a current evaluation of the nutrient and primary productivity regime utilizing ^{15}N and ^{13}C stable isotope tracer techniques in the context of the physical and hydrological environment, to not only assess current conditions, but to provide a baseline for future predictions.

DESCRIPTION OF PLUME REGION

The general circulation pattern at the mouth of the Chesapeake Bay as it enters the coastal ocean has been described as a two-way exchange; with seawater flowing in at depth at the southern side and lower salinity water flowing out at the surface along the entire mouth of the Bay (Valle-Levinson et al. 1998). This flow is a combination of circulation due to density gradients, wind-induced flow, bathymetry, and tides (Valle-Levinson and Lwiza 1997; Valle-Levinson et al. 1998; Guo and Valle-Levinson 2007). The Chesapeake Bay plume has been described as a buoyancy jet resulting from the Chesapeake Bay subtidal outflow entering the shelf region, turning anticyclonically, and being trapped against the coast due to the Coriolis force (Valle-Levinson and Lwiza 1997; Valle-Levinson et al. 1998). Wind stress and freshwater flow play major roles in the temporal and spatial distribution of the low salinity (< 30) waters as they move from the Bay mouth (Johnson et al. 2001; Valle-Levinson et al. 2001). Just south of the Bay mouth, alongshore winds from the north, common between fall and spring, can result in coastal downwelling which serves to strengthen the outflow jet and confine the southward flow of water near the southern Virginia coast. Under this condition, inputs to the coastal ocean from the Chesapeake Bay may be limited in the horizontal (west to east) extent. In the summer, winds blowing from the south result in offshore Ekman transport, thus broadening the plume, allowing for nutrients to penetrate west to east exiting the mouth of the Bay, and providing conditions favorable for coastal upwelling near the Bay mouth (Johnson et al. 2001).

In addition to wind-driven seasonal upwelling and downwelling-favorable events, evidence has shown that density fronts driven by differences in temperature and salinity can form along the Virginia coast, similar to those occurring in the Delaware Bay (Sanders and Garvine 1996; Marmorino et al. 2000). These fronts typically occur near Cape Henry and are more typical during high tide and under high flow conditions (e.g., spring). During these events, dense oceanic water is trapped between the coast and the plume and subducts underneath the surface water within timescales of a tidal cycle (Marmorino et al. 2000). Associated dissolved and particulate material from dense inshore water can then become entrained in the northward flow, potentially moving back into the estuary (Marmorino et al. 2000). The complex circulation that characterizes coastal environments is influenced by and modifies the effects of the estuary on coastal nutrient and C dynamics.

METHODS

In order to place nutrient concentrations, N cycling, and primary productivity into the context of the physical environment of the Chesapeake Bay outflow plume, and to better understand how the Bay impacts the surrounding coastal zone, we measured nutrient concentrations, N uptake rates, and primary productivity rates in north-south and west-east transects exiting the mouth of the Chesapeake Bay during both high and low freshwater flow conditions, over 4 seasons and 3 years. We measured these at two biologically relevant depths, near the surface and at the chlorophyll fluorescence maximum. Five stations were sampled, one within the Bay mouth area (BM), three along the VA coast designated as plume stations (PL1, PL2, and PL3) and one station, depending upon physical factors, that was either inside or outside the influence of the outflow plume at the Chesapeake Light Tower (CLT) (Fig. 2.1).

Freshwater discharge was calculated as the sum of freshwater flow from the Susquehanna, Potomac, and James Rivers and multiplied by a factor of 1.22 to account for the influence of the remaining tributaries, this is a similar calculation as put forth by Austin (2002). The Susquehanna, Potomac, and James Rivers account for approximately 50%, 18%, and 14%, respectively of the total freshwater flux entering the Chesapeake Bay (Hargis 1981) and therefore, the factor of 1.22 was devised by dividing 100 by the total percentage for the three major rivers (Eq. 2.1). Daily flow rates were then estimated based on the sum of the daily flow rates for each river, multiplied by 1.22 (Eq. 2.2).

$$100/\,(50\% + 18\% + 14\%) = 1.22 \qquad (2.1)$$

$$(\text{Susquehanna} + \text{Potomac} + \text{James}) \times 1.22 = \text{Daily flow rate into Bay} \qquad (2.2)$$

Daily flow rates from the three rivers were obtained at three USGS monitoring stations near Conowingo, MD for the Susquehanna, Washington DC for the Potomac, and Cartersville, VA for the James (http://va.water.usgs.gov/chesbay/RIMP/). Freshwater flow rates prior to each cruise are reported as the 10-day average of the flow as derived above, prior to each cruise date.

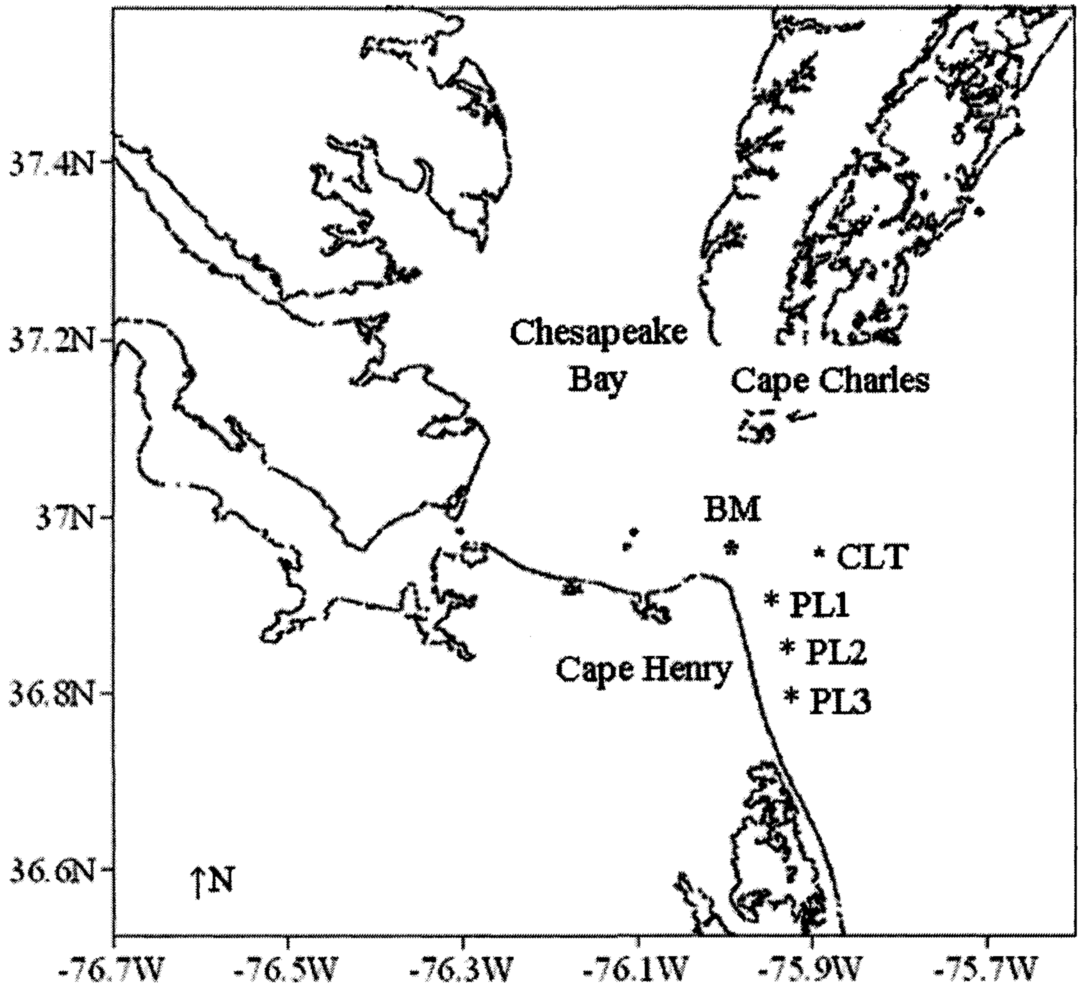

Fig. 2.1. Chesapeake Bay outflow plume stations. Bay mouth (BM), Chesapeake Light Tower (CLT), Plume 1 (PL1), Plume 2 (PL2), and Plume 3 (PL3) are shown.

Research cruises were conducted aboard Old Dominion University's *R/V Fay Slover* in May, June, November 2005, April, August, September, November 2006, and March, April, July, and August 2007. Cruises were conducted aboard the University of Delaware's *R/V Cape Henlopen* during March and July 2005, and aboard the *R/V Hugh R. Sharp* in May, July, and October 2006. Hydrography was measured using the ships' conductivity, temperature, and depth (CTD) sensors (SeaBird electronics). Depth profiles of temperature, salinity, density, light attenuation, dissolved oxygen, and Chl *a* fluorescence were collected at each station. At each station, water samples were collected from the near surface (0 – 2 m) and at the fluorescence maximum (4.5 – 18 m) when the water column was stratified and at the surface and 1 m above the bottom when the water column was well mixed, using Niskin bottles mounted on the CTD rosette.

Nutrient samples were pumped from Niskin bottles using a peristaltic pump, acid-washed Tygon tubing, and a 0.2 μm polysulfone cartridge filter conditioned by pumping for 5 minutes with sample water prior to collection of filtered water for nutrient analyses. Filtered samples were collected directly into duplicate acid-washed high density polyethylene (HDPE) bottles and frozen until analysis. NO_3^-+ NO_2^-, NO_2^-, urea, PO_4^{3-}, and silicate (SiO_4^{4-}) were analyzed on an Astoria Pacific nutrient auto-analyzer according to manufacturer specifications using standard colorimetric methods (Parsons et al. 1984; Price and Harrison 1987). NO_3^- was calculated as the difference between NO_3^- + NO_2^- (measured on the auto-analyzer after reduction by a cadmium coil) and NO_2^-. The detection limits for each analysis were: NO_3^- + NO_2^- : 0.02 μmol L^{-1}, NO_2^-: 0.02 μmol L^{-1}, PO_4^{3-}: 0.02 μmol L^{-1}: SiO_4^{4-}: 0.05 μmol L^{-1}: urea N: 0.05 μmol L^{-1}. The manual phenol-hypochlorite method coupled with spectrophotometric detection at a wavelength of 640 nm using a 10 cm cell was used to measure NH_4^+ concentrations; the detection limit was 0.01 μmol L^{-1} (Solorzano 1969). Total dissolved nitrogen (TDN) was analyzed as NO_3^- + NO_2^- using the colorimetric methods described above on the Astoria Pacific auto-analyzer after persulfate oxidation and had a detection limit of 0.5 μmol L^{-1} (Valderrama 1981). DON was calculated as the difference between TDN and DIN concentrations and standard error propagation was used to calculate standard deviations in DON concentrations. Dissolved free amino acid's (DFAA's) were analyzed via high performance liquid chromatography (HPLC) and a detection limit of 0.01 μmol L^{-1} (modified from Cowie and Hedges 1992). DFAA N was calculated based on the N content of the free amino acids quantified by HPLC. For all of these nutrients, triplicate analyses were conducted for the duplicate water samples, and results were accepted if they had a relative standard deviation less than 10%. Averages and standard deviations were reported for the original duplicate samples (Appendix tables A.1 – A.5).

DIC and alkalinity samples were collected unfiltered in combusted glass vials with 2% mercuric chloride and sealed without headspace and refrigerated at 4 °C until analysis for all 2005 and 2006 research cruises. Collection and sample analysis were based on the protocols set forth by Johnson et al. (1985). DIC measurements were made on an UIC Inc. 5014 CO_2 coulometer, and measured against a seawater standard with an accuracy of 1 μmol L^{-1}, and a precision of 0.5 μmol L^{-1} and DIC concentrations were used as the ambient concentrations for primary productivity uptake calculations. Alkalinity was measured on the same samples using a Brinkmann Titrino titrator (Dickson 1981).

Between 50 mL and 250 mL of whole water, depending upon biomass, was collected and filtered in duplicate onto pre-combusted (2 hours at 450°C) GF/F filters for analysis of particulate C and N (PC and PN), and Chl *a*. Filters were folded and placed into cryovials and frozen. PN and PC samples were analyzed within three months of acquisition by placing them in a drying oven (40 °C) for 48 hours, and pelletizing them into tin discs for analysis on a Europa 20/20 mass spectrometer equipped with an automated N and C analyzer (ANCA) preparation module. The limit of detection for N is 3 μg and for C is 37.5 μg. Routine measurements for atom % N and C were made against a standard, sucrose for C and ammonium sulfate for N. These standards were periodically checked against DL-asparagine, a standard from the National Institute of Standards and Technology, with accepted values within 0.1% of the measured standard. Chl *a* samples were analyzed within 48 hours of sample collection by extracting the filter in 90% acetone for 24 hours and measuring fluorescence in the extract on a Turner fluorometer. This method measures Chl *a* in the presence of Chl *b* and phaeophytin, but is only sensitive to Chl *a* concentrations (Welschmeyer 1994). The fluorometer was calibrated daily using a solid standard and the detection limit was 0.003 μg chl L^{-1}.

Rates of net N and C uptake and primary productivity were made in whole water samples using single or dually labeled highly enriched (96-99%) ^{15}N and ^{13}C-labeled compounds (Glibert and Capone 1993; Mulholland et al. 2002). To initiate uptake experiments, ^{15}N and/or ^{13}C was added to 250 or 500 mL whole water samples in polyethylene terephthalate (PETG) bottles at approximately 10% of the ambient nutrient concentration for the following substrates: $^{15}NO_3^-$, $^{15}NO_2^-$, $^{15}NH_4^+$, urea (dually labeled ^{15}N and ^{13}C) and glutamate (dually labeled ^{15}N and ^{13}C). Primary productivity was measured using ^{13}C-labeled bicarbonate in both light and dark bottles (Mulholland and Capone 2001). Bottles were then placed into incubators supplied with flow-through seawater to keep the bottles at or near ambient temperature. Neutral density screens were placed over each incubator to simulate *in situ* light levels. A hand held PAR sensor was used to measure the incident light level in the incubators. Measurements suggest that each layer of screen is capable of reducing incoming radiation by about 50%. Based on preliminary results, ^{15}N incubations were terminated after 4 hours. A 4-hour incubation period was short enough to avoid nutrient depletion or isotopic equilibrium but long enough to allow for detection of isotopic enrichment of the particulate pool. In the case of ^{13}C-labeled bicarbonate experiments, incubations were conducted for 4 and 24 hours. In a few cases, 24-hour incubations were not feasible so only 4 hour incubations were reported. For 4-hour incubations, daily rates were calculated by multiplying by 12 h, and for 24-hour incubations, daily rates were calculated by multiplying by 24 h. Daily rates of photosynthetic C uptake estimated from 4- and 24-hour incubations were generally within good agreement (< 10 % difference). Limitations to incubations, particularly on the *R/V Fay Slover*, included shading from the ship that occurred with no consistency. Incubations were terminated by gentle filtration onto GF/F filters. The filters were frozen and brought back to the lab where they were analyzed within three months of collection. Prior to analysis, filters were dried at 40 °C for two days in a drying oven. The filters were then pelletized in tin discs and analyzed using a Europa 20/20 mass spectrometer equipped with an automated N and C analyzer (ANCA) preparation module.

Uptake rate calculations for both ^{15}N (Eq. 2.3) and ^{13}C (Eq. 2.4) tracer experiments are shown below and were based on a mixing model and equations from Montoya et al. (1996) and Orcutt (2001).

$$\text{N uptake} = \frac{(\text{atom \% PN})_{\text{final}} - (\text{atom \% PN})_{\text{initial}}}{(\text{atom\% enrichment N source pool}) - (\text{atom\% PN})_{\text{initial}} \times \text{time}} \times [\text{PN}] \quad (2.3)$$

$$\text{C uptake} = \frac{(\text{atom \% PC})_{\text{final}} - (\text{atom \% PC})_{\text{initial}}}{(\text{atom\% enrichment C source pool}) - (\text{atom\% PC})_{\text{initial}} \times \text{time}} \times [\text{PC}] \quad (2.4)$$

In these equations, atom % PN (PC) represents the atom % ratio of ^{15}N:^{14}N or ^{13}C:^{12}C in the initial or ambient and final (post-incubation) sample and [PN] and [PC] are the concentrations of PN and PC in μmol L^{-1}, respectively. Atom % enrichment is the enrichment of the source nutrient pool at the beginning of the experiment and is calculated as shown in Eq. 2.5.

$$\text{Atom\% enrichment (\%)} = \frac{([\text{tracer}] \times \text{atom\%tracer})+([\text{ambient N or C}] \times \text{atom\%initial})}{[\text{tracer}] \times [\text{ambient N or C}]} \qquad (2.5)$$

All samples were collected in duplicate and averages and standard deviations for all parameters were reported in Appendix Tables A.1 – A.5. In order to compare concentrations and rates across depth, season, station, or plume type, one way ANOVA tests were run on the averages and standard deviations considering a sample size of n (Table 2.1). If there were significant differences among averages, a Tukey test was run to determine which averages were significantly different from one another. P values less than 0.05 were significant. Relationships between two parameters were analyzed using linear regression and Pearson's product moment correlation, correlations for all pooled data are shown in Appendix table A.6. Significant differences had p values less than 0.05.

Table 2.1. Sample size (n) used to average across season, station, or plume type. Significant differences were distinguished with biomass, nutrient concentrations, and uptake rates.

Season	n	Station	n	Plume type	n
Spring	30	BM	32	Jet-like	48
Summer	58	PL1	32	Diffuse-estuarine	50
Fall	26	PL2	28	Oceanic-influenced	32
Winter	16	PL3	8		
		CLT	28		

RESULTS

HYDROGRAPHIC REGIME

This study spanned three normal flow years which, as defined by the USGS, are within the 25th and 75th percentile for annual flow rates since measurements began in 1937 (http://md.water.usgs.gov/monthly/bay.html#wymean). The average freshwater flow entering the Bay, calculated as mentioned above (Eqs. 2.1 and 2.2) in 2005 was 68 x 10^{10} m^3 y^{-1}, in 2006 it was 69 x 10^{10} m^3 y^{-1}, and in 2007 it was 54 x 10^{10} m^3 y^{-1}. Although 2007 had similar total flows to 2005 and 2006 and was still considered a normal flow year, there was a summer drought and the distribution of rainfall events over the year was sporadic (Fig. 2.2). During 2005, there were very high to above average flows during spring months, but the rest of the year freshwater flow was below the normal average (Fig. 2.2). March 2006 had the lowest flow for that month since 1937 when measurements were first made, while January, June, July, and September 2006 ranked among the ten highest months on record, according to the USGS (http://md.water.usgs.gov/monthly/bay.html#wymean). In 2007, there was high freshwater flow during January and February; however there was a sustained drought during the remaining part of the year (Fig. 2.2).

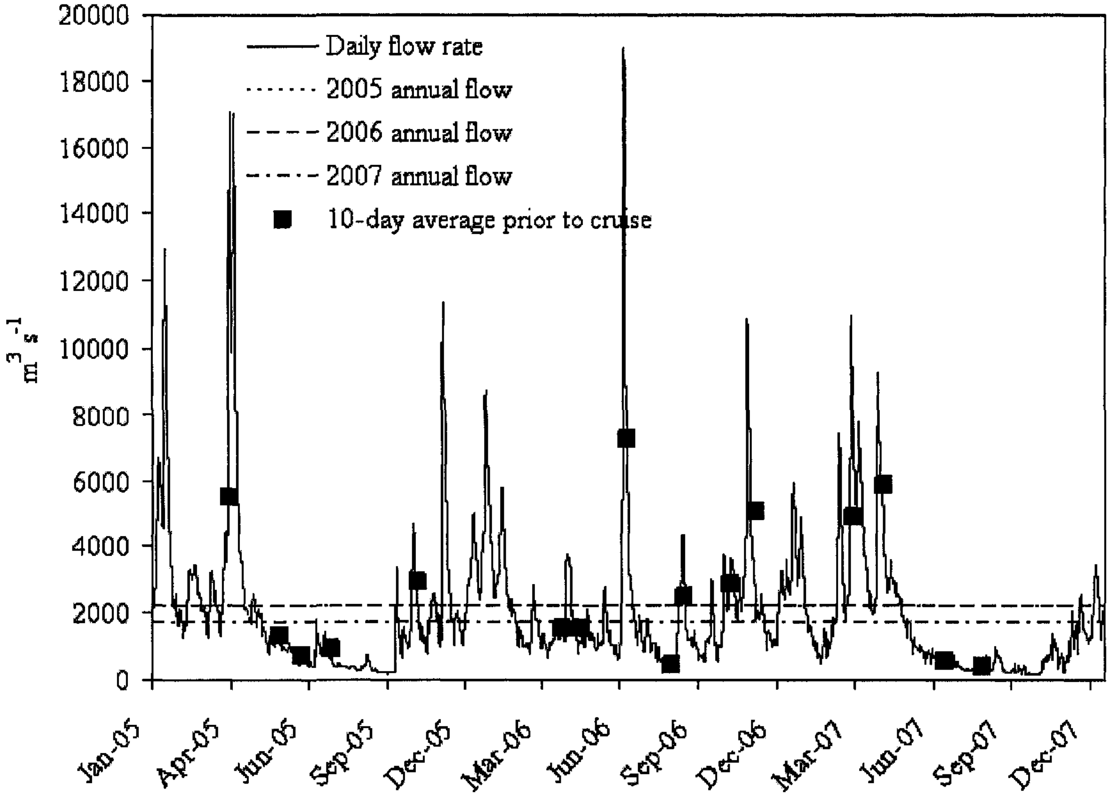

Fig. 2.2. Freshwater outflow entering the Chesapeake Bay from the Susquehanna, Potomac, and James Rivers for 2005 to 2007. A multiplication factor of 1.22 accounts for the remaining tributaries, including 10-day averaged flow for each sampling date, the average annual flow for 2005, the average annual flow for 2006, and the average annual flow for 2007.

Surface salinity and satellite imagery (when available) of temperature were used to locate the outflow plume during each cruise. Large-scale discharge events and the predominant meteorological conditions (upwelling versus downwelling-favorable winds) rather than seasonality were most important in determining the type and position of the outflow plume. Based on surface salinity, freshwater discharge, wind direction, and surface temperature at each station, three plume morphotypes were defined: jet-like (Jet), diffuse with an estuarine influence (DE), or diffuse with an oceanic influence (OI) (Table

2.2). There was no significant relationship between freshwater flow and salinity for all stations at both depths. However, sampling occurred during different tidal stages, and no one plume type could be attributed to a particular tidal cycle.

A jet-like plume, when water exited the Bay to the south and remained confined to the VA coastline, was characterized by high salinity at the CLT station (28 – 31), lower salinity at the BM, PL1, PL2, and PL3 stations (15 – 25), and the 10-day averaged flow rate into the Bay, as calculated from Eqs. 2.1 and 2.2, ranged between 559 and 5498 $m^3 s^{-1}$ (Table 2.2). When the plume was jet-like, winds were almost always from the north, with one exception in March 2007, when winds were coming from the south (Table 2.2). Remote sensing of sea surface temperature shows a jet-like plume, defined by warm temperatures exiting the mouth of the Bay and hugging the southern VA coastline (Fig. 2.3). The jet-like plume scenario was observed during late winter/early spring and fall in 6 out of the 16 research cruises (Table 2.2).

Table 2.2. Date, 10-day averaged freshwater flow as calculated from Eqns. 2.1 and 2.2, surface salinity ranges at the BM, PL1, PL2, and PL3 stations, surface salinity at the CLT station, 10-day averaged wind speed and direction from the Chesapeake Bay Bridge Tunnel (NOAA CO-OPS), and type of plume observed for each sampling event. 'Jet': Jet-like plume type, narrow lens of estuarine water exiting Bay mouth: 'DE': Diffuse-estuarine plume type, estuarine waters broadened out past the CLT: 'OI': Oceanic influenced plume type, oceanic waters intruding on the typical plume stations. Standard deviations are in parenthesis.

Date	Freshwater flow, 10-day average $m^3 s^{-1}$	Surface salinity range: BM, PL1, PL2, and PL3	Surface salinity at CLT	Wind speed,10-day average $m s^{-1}$	Wind direction	Plume type
March 05	5366 (4649)	20 - 22	31	3.8 (1.9)	northwesterly	Jet
May 05	1266 (193)	15 – 22	28	3.6 (1.7)	northerly	Jet
June 05	693 (186)	20 – 24	n.d.	3.4 (1.8)	southerly	DE
July 05	917 (288)	24 – 26	27	3.0 (1.3)	southerly	DE
Nov 05	2874 (1101)	27 – 30	34	4.2 (2.4)	northeasterly	OI
April 06	1460 (179)	25 – 26	29	2.4 (1.5)	southerly	OI
May 06	1482 (416)	23 – 29	n.d.	4.4 (2.3)	northerly	Jet
July 06	7037 (6228)	22 – 27	26	3.9 (1.7)	southerly	DE
Aug 06	437 (113)	24 – 25	29	3.1 (1.8)	southerly	OI
Sept 06	2466 (1363)	23 – 25	30	4.4 (2.4)	southerly	DE
Oct 06	2796 (732)	24 – 31	30	5.1 (2.1)	southeasterly	OI
Nov 06	4919 (2441)	17 – 20	31	4.6 (3.1)	northerly	Jet
March 07	4792 (3547)	17 – 24	32	9.0 (3.8)	southerly	Jet
April 07	5707 (2053)	18 – 21	21	9.2 (5.4)	southeasterly	DE
July 07	545 (128)	22 – 25	30	6.6 (2.8)	northwesterly	Jet
Aug 07	373 (94)	24 - 31	30	6.1 (2.6)	southerly	DE

Number of cruises	Avg flow ± s.d.	Avg sal. ± s.d.	Avg sal. ± s.d.	Avg w.s. ± s.d.	Dominant w.d.	Plume type
6	3062 ± 2182	21.3 ± 3.9	30.4 ± 1.5	5.3 ± 2.1	northerly	Jet
6	2866 ± 2841	23.7 ± 3.4	26.8 ± 3.7	5.0 ± 2.3	southerly	DE
4	1892 ± 1167	26.5 ± 2.7	30.5 ± 2.4	3.7 ± 1.2	southerly	OI

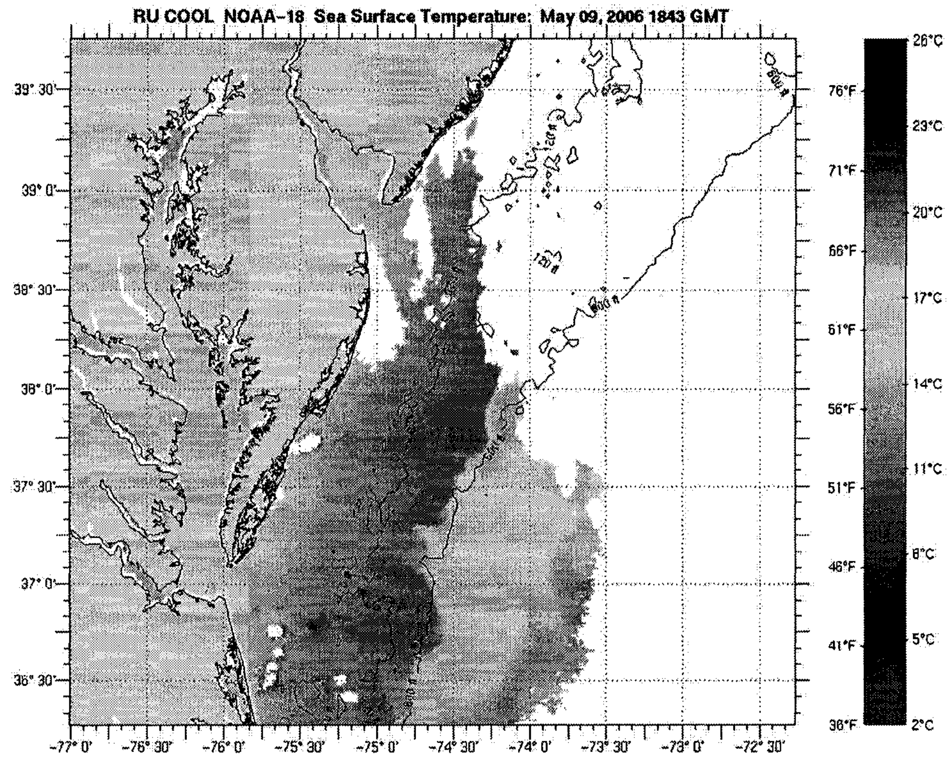

Fig. 2.3 May 2006 satellite imagery of sea surface temperature. This is an example of a jet-like plume with warm waters exiting the Bay mouth, turning south and hugging the VA coastline. Satellite imagery was downloaded from Rutgers University, RUCOOL website (http://marine.rutgers.edu/cool/sat_data/?nothumbs=0).

Diffuse plumes with a distinct estuarine influence occurred when plume waters exited the mouth of the Bay and then dispersed to the east. When the plume was diffuse, salinity at the CLT was 21 – 30, lower than that observed when the plume was jet-like. Similar salinity ranges were observed at the BM, PL1, PL2, and PL3 stations (18 – 31) (Table 2.2). Low salinities were observed at all stations when the plume was diffuse, although during August 2007, after the prolonged drought, the PL3 station had higher salinity suggesting it was out of the influence of the plume. In the diffuse-estuarine plume type, the extent of the low salinity waters extended further to the east in comparison to the jet-like plume. The 10-day averaged flow rates during diffuse-estuarine plume conditions ranged between 382 and 7210 m^3 s^{-1}, not significantly different than those observed for the jet-like plume, however winds were always coming from the south, creating upwelling favorable conditions that counteracted the influence of the high freshwater flow (Table 2.2). Satellite imagery of sea surface temperature demonstrating the diffuse-estuarine plume scenario in July 2006 is shown in Fig. 2.4. The diffuse-estuarine plume was defined by the warm temperatures exiting the mouth of the Bay extending south along the coast but also penetrating to the east (Fig. 2.4). The diffuse-estuarine plume scenario was observed during late spring, summer, and early fall in 6 out of the 16 research cruises (Table 2.2).

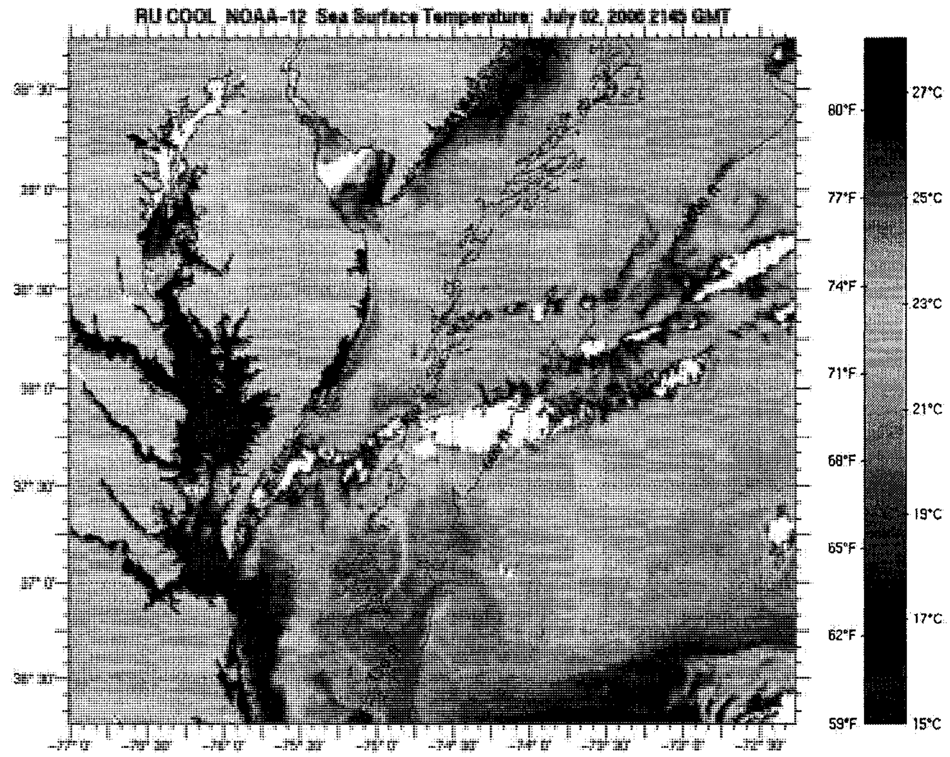

Fig. 2.4. July 2006 satellite imagery of sea surface temperature. This is an example of a diffuse plume with an estuarine influence with warm waters exiting the Bay mouth from west to east. Satellite imagery was downloaded from Rutgers University RUCOOL website (http://marine.rutgers.edu/cool/sat_data/?nothumbs=0).

A third plume type was observed, wherein there was a pronounced oceanic influence. Low salinity water was not observed near the Bay mouth, rather high salinity, oceanic water was prominent along both the north-south and the west-east axes. This was observed when salinity at the CLT (29 – 34) was higher than that observed during the jet-like plume and the diffuse-estuarine plume, and ranges at the BM, PL1, PL2, and PL3 (24 – 31) were also higher (Table 2.2). The 10-day averaged freshwater flow rates ranged between 448 and 2944 $m^3 s^{-1}$, lower than those observed for the jet-like and diffuse-estuarine plume types, and winds were almost always coming from the south, promoting upwelling favorable conditions, with one exception during November 2005 when winds were coming from the northeast. However, during November 2005, freshwater flow from the James River was extremely low (50 ± 10 m^3 s^{-1}) 10 days prior to sampling, therefore although the wind direction was not upwelling favorable, freshwater flow was low so that low salinity waters were not penetrating the coastal region to the extent that a jet-like or diffuse-estuarine plume type would (Table 2.2). Satellite imagery of sea surface temperature of the oceanic influenced plume type in April 2006 is shown in Fig. 2.5. The oceanic-influenced plume was characterized by cooler temperatures surrounding the mouth of the Bay and the southern VA coastline (Fig. 2.5), upwelling favorable conditions, and minimal influence of low salinity water. The oceanic influenced plume type was observed during spring, summer, and fall in 4 out of the 16 research cruises (Table 2.2).

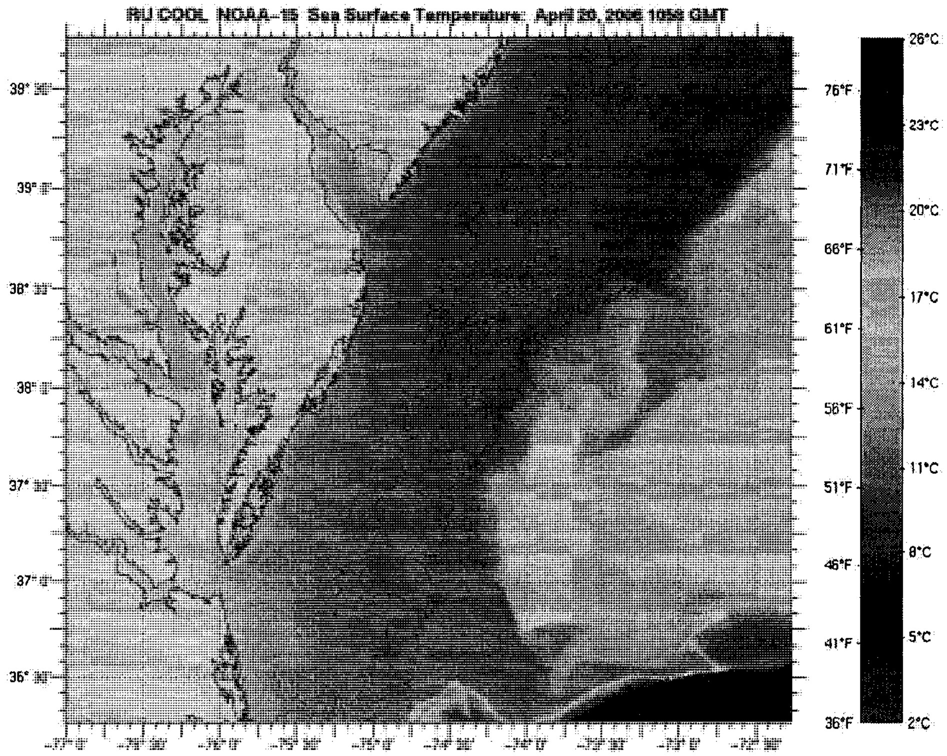

Fig. 2.5. April 2006 satellite imagery of sea surface temperature. It is an example of a diffuse plume with an oceanic influence. Cooler waters appear to be surrounding the mouth of the Bay and the southern coastline of VA. Satellite imagery was downloaded from Rutgers University RUCOOL website (http://marine.rutgers.edu/cool/sat_data/?nothumbs=0).

Conservative mixing between estuarine and oceanic waters was observed in the relationship between alkalinity and salinity in pooled data from 2005 and 2006 (Fig. 2.6). A significant positive linear relationship between salinity and alkalinity was observed for both depths ($R = 0.638$; $p < 0.05$; Fig. 2.6), suggesting conservative mixing between the oceanic and estuarine end members. These results were consistent with previous results demonstrating conservative mixing between inflowing Atlantic waters and outflowing James River and Chesapeake Bay waters when flows were moderate (Wong 1979).

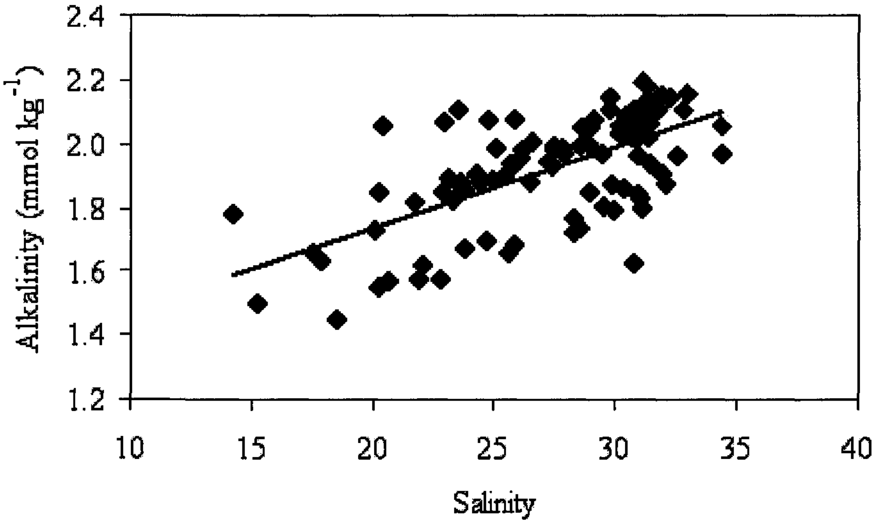

Fig. 2.6. Alkalinity versus salinity for all stations and both depths. Conservative mixing ($R = 0.638$; $p < 0.05$) is apparent for 2005 – 2006 data.

In order to assess the wide variability observed in measurements of physical parameters and nutrient and biological parameters, results for biomass, nutrients, and C and N uptake rates were divided into seasonal comparisons, station location comparisons, and plume type comparisons. The cruises used to average across seasons were as follows: Spring – 5/05, 4/06, 5/06, 4/07; Summer – 6/05, 7/05, 7/06, 8/06, 7/07, 8/07; Fall – 11/05, 9/06, 10/06; Winter – 3/05, 11/06, 3/07. Station locations were CLT, BM, PL1, PL2, and PL3, however PL3 had fewer data points than the other stations and was often outside the plume influence so results should be interpreted with caution. Plume types were the jet-like plume, the diffuse-estuarine plume, and the oceanic influenced plume.

NUTRIENT REGIME

Dissolved inorganic nitrogen (DIN = $NH_4^+ + NO_2^- + NO_3^-$) concentrations were significantly greater during the fall compared to the spring, summer and winter, mainly due to NO_3^- and NO_2^- (ANOVA; Tukey test; $p < 0.05$; Fig. 2.7). The highest DIN concentrations were observed in the late fall 2006 (1.8 – 7.5 µmol L^{-1}; Appendix table A.1). During the spring, NO_3^- was positively correlated with temperature ($R = 0.431$; $p < 0.05$) and Chl *a* ($R = 0.513$; $p < 0.05$), and negatively correlated with salinity ($R = -0.568$; $p < 0.05$). No significant relationships were observed between NH_4^+ or NO_2^- and temperature, salinity, or Chl *a* concentrations during spring ($p > 0.05$). No significant relationships were observed between DIN and temperature, salinity, or Chl *a* concentrations ($p > 0.05$) during summer. During fall, NO_3^- was negatively correlated with temperature ($R = -0.738$; $p < 0.05$) and salinity ($R = -0.747$; $p < 0.05$) and positively correlated with Chl *a* ($R = 0.491$; $p < 0.05$). Also during fall there was a significant positive linear relationship between NO_2^- and Chl *a* ($R = 0.701$; $p < 0.05$), but not with temperature or salinity ($p > 0.05$). No significant linear relationships were observed between NH_4^+ and temperature, salinity, or Chl *a* during fall ($p > 0.05$). During winter, the only significant relationships (negative) observed were between salinity and urea ($R = -0.576$; $p < 0.05$) and salinity and SiO_4^{4-} ($R = -0.568$; $p < 0.05$).

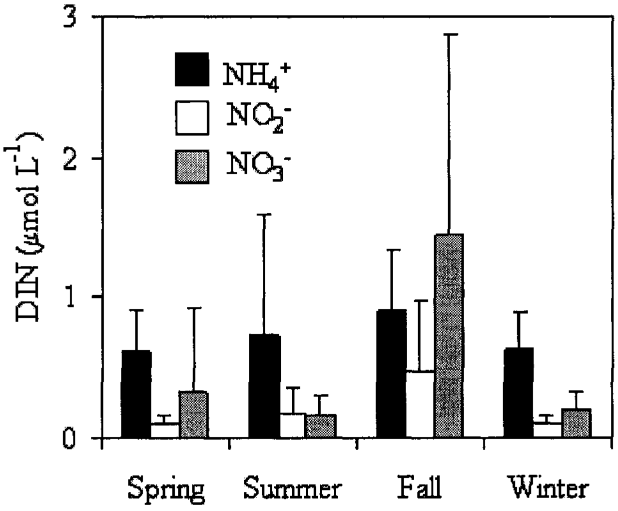

Fig. 2.7. DIN concentrations (NH_4^+; NO_2^-; NO_3^-) averaged for all seasons. Error bars represent standard deviations. Fall DIN concentrations were significantly greater than spring, summer, and winter DIN concentrations.

Total DIN concentrations as well as concentrations of individual compounds (NH_4^+, NO_2^-, or NO_3^-), were averaged for each station and there were no significant differences among stations (Fig. 2.8). At the BM and PL2 stations, average NH_4^+ concentrations were significantly greater than average NO_2^- concentrations (ANOVA; Tukey test; $p < 0.05$). No significant differences were observed between average NH_4^+, NO_2^-, and NO_3^- concentrations at the PL1 station (ANOVA; $p > 0.05$). At the CLT station, average NH_4^+ concentrations were significantly greater than average NO_2^- and NO_3^- concentrations, and average NO_3^- concentrations were significantly greater than average NO_2^- concentrations (ANOVA; Tukey test; $p < 0.05$). When relating freshwater flow to DIN concentrations at the BM station, and salinity and temperature to DIN concentrations at the stations outside the Bay mouth, there were no significant linear relationships. There was a significant negative linear relationship between salinity and DIN concentrations when all the station data from all the cruises was pooled, although it was a weak correlation (R = -0.239; Fig. 2.9; Appendix table A.6). Of the three DIN compounds, only NO_3^- had a significant negative linear relationship with salinity for all stations at both depths, but again, the correlation was weak (R = -0.350; Fig. 2.9; Appendix table A.6). A significant positive linear relationship was also found between DIN (R = 0.402) (specifically NO_3^-; R = 0.413) and Chl *a* concentrations (Fig. 2.10).

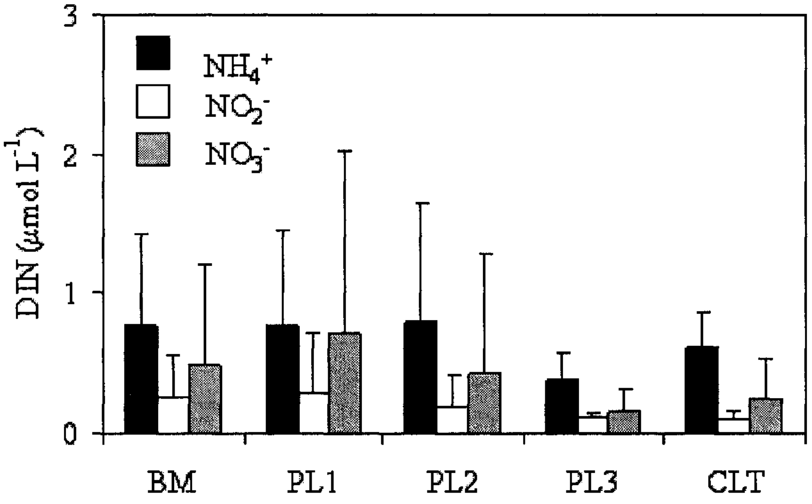

Fig. 2.8. Average DIN concentrations (NH_4^+; NO_2^-; NO_3^-) for each station. Error bars represent standard deviations. There were no significant differences between mean DIN concentrations amongst stations.

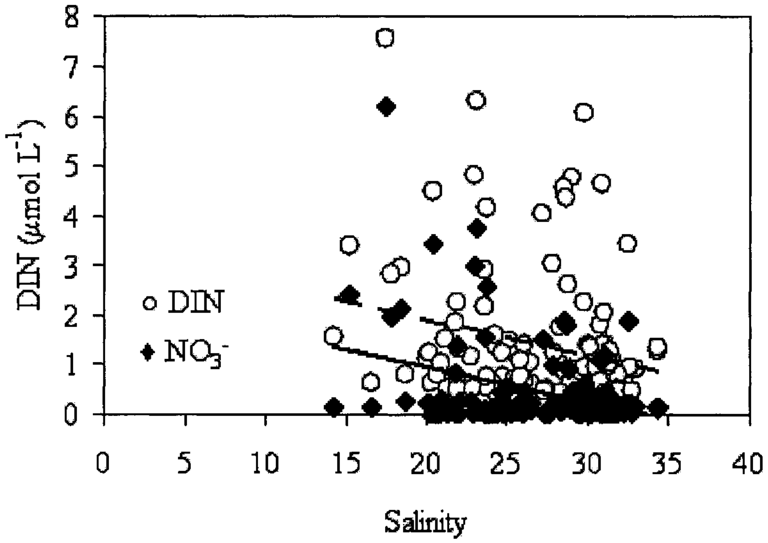

Fig. 2.9. Total DIN and NO_3^- concentrations versus salinity for all stations at both depths. There were significant negative linear relationships between salinity and DIN (dashed line; R = -0.239) and salinity and NO_3^- (solid line; R = -0.350).

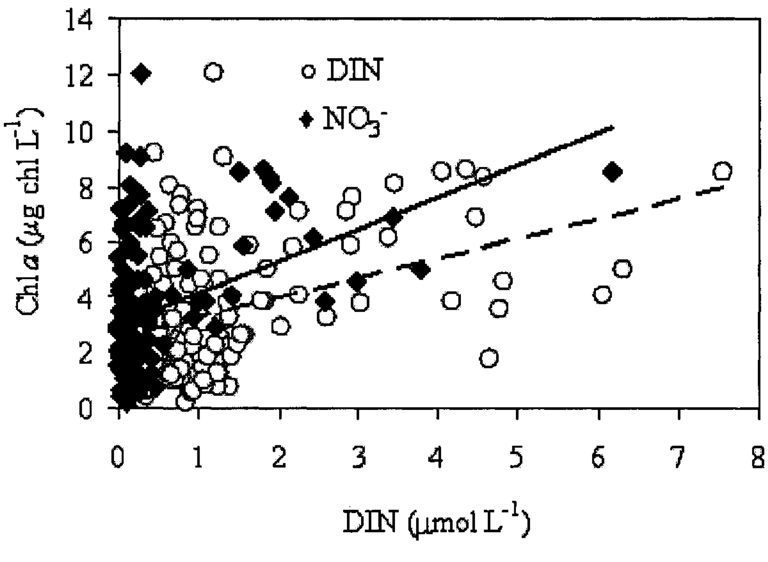

Fig. 2.10. Chl *a* concentrations versus DIN and NO_3^- concentrations for all stations at both depths. There were significant positive linear relationships between DIN (dashed line; R = 0.402) and Chl *a* and NO_3^- (solid line; R = 0.413) and Chl *a*.

There was no significant difference in DIN concentrations between plume types (ANOVA; $p > 0.05$; Fig. 2.11). Of the individual DIN compounds, NO_2^- concentrations were significantly greater when there was an oceanic influenced plume compared to the jet-like and diffuse-estuarine plume type (ANOVA; Tukey test; $p < 0.05$; Fig. 2.11). In contrast, NO_3^- concentrations were significantly greater when the plume was jet-like (ANOVA; Tukey test; Fig. 2.11). There were no significant differences in NH_4^+ concentrations with respect to plume type (ANOVA; $p > 0.05$; Fig. 2.11). DIN concentrations versus salinity plots had a significant negative linear relationship when the plume was jet-like ($R = -0.472$; Fig. 2.12) but not for other plume types. No significant relationships were observed between temperature and DIN concentrations with respect to plume types ($p > 0.05$).

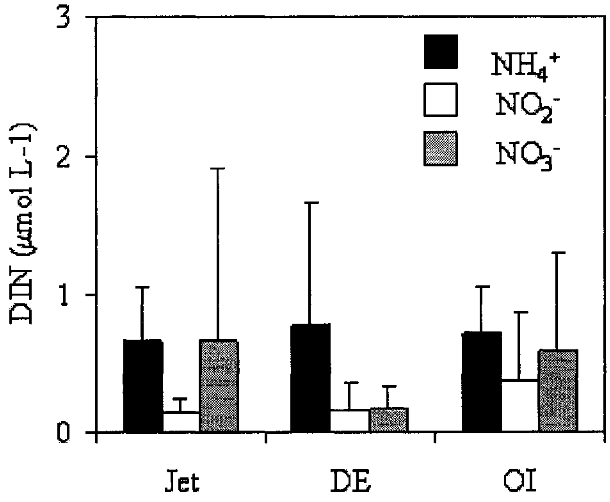

Fig. 2.11. Average DIN concentrations (NH_4^+; NO_2^-; NO_3^-) for each plume type. Error bars represent the standard deviations. DIN and NH_4^+ concentrations were not significantly different among plume types but NO_2^- concentrations during the oceanic influenced scenario were significantly greater than during the jet-like and diffuse-estuarine plume type, and NO_3^- concentrations were significantly greater during the jet-like plume compared to the diffuse-estuarine plume.

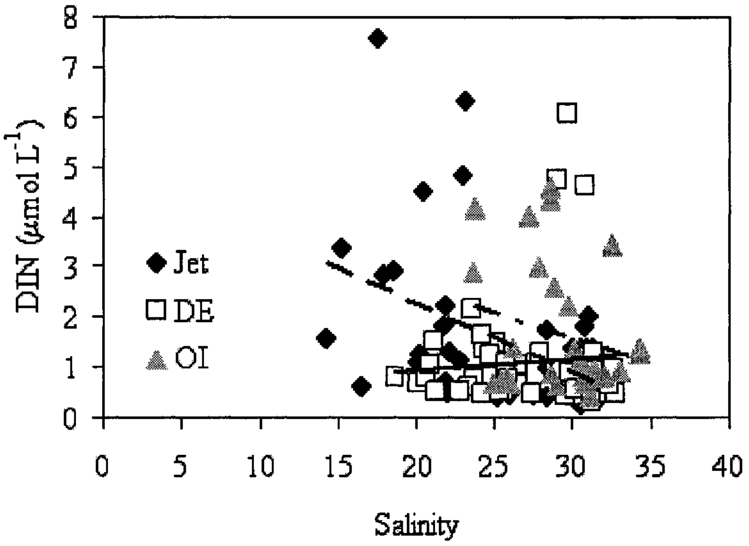

Fig. 2.12. DIN concentrations versus salinity for the jet-like plume, diffuse-estuarine plume, and oceanic influenced plume. Linear regression showed a significant negative relationship between salinity and DIN concentrations for the jet-like plume (dashed line; R = -0.472) but not for the DE (solid line) or OI (dot-dashed line) plume types.

PO_4^{3-} concentrations ranged from below the limit of detection (0.02 μmol L^{-1}) to about 0.8 μmol L^{-1} with no significant differences among seasons (Appendix table A.2). SiO_4^{4-} concentrations ranged from below the limit of detection (0.05 μmol L^{-1}) to almost 25 μmol L^{-1} with highest concentrations observed in the summer and fall (Appendix table A.2). Ratios of DIN to dissolved inorganic phosphorus (DIP) concentrations were less than 16:1 during all seasons except for late fall 2006, and late winter 2007 (Fig 2.13). Ratios of DIN to SiO_4^{4-} concentrations were less than 1 during all seasons except for spring 2005 and early spring 2007, fall 2006, and winter 2005 (Fig. 2.14). These two relationships suggested that the coastal region was N limited most of the time.

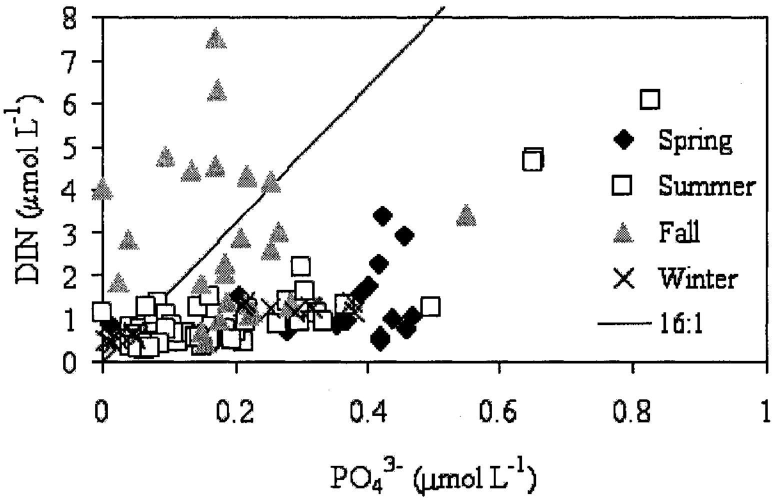

Fig. 2.13. DIN concentrations versus PO_4^{3-} concentrations for spring, summer, fall, and winter for all stations and all depths. The solid line indicates the 16:1 ratio for DIN to PO_4^{3-}.

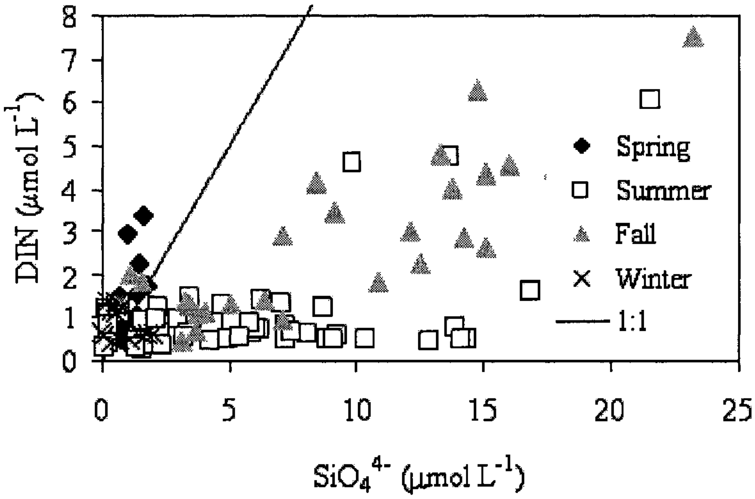

Fig. 2.14. DIN concentrations versus SiO_4^{4-} concentrations for spring, summer, fall, and winter for all stations and all depths. The solid line indicates the 1:1 ratio for DIN to SiO_4^{4-}.

DON concentrations were found to be significantly lower in the summer than during other seasons (ANOVA; Tukey test; $p < 0.05$; Fig. 2.15). This was different than what was observed for DIN concentrations, where fall concentrations were significantly greater than the other seasons (Fig. 2.7). The sum of urea N and DFAA N ranged from 0.12 to 1.5 μmol N L^{-1} (Appendix table A.1) and represented, on average, 5 % of the DON pool. Urea N concentrations were significantly greater in the summer compared to the spring and DFAA N concentrations were significantly greater in the winter compared to the other seasons (Fig. 2.15). There were no significant relationships between DON (or urea N and DFAA N) concentrations and salinity or temperature for the pooled data ($p > 0.05$; Appendix table A.6).

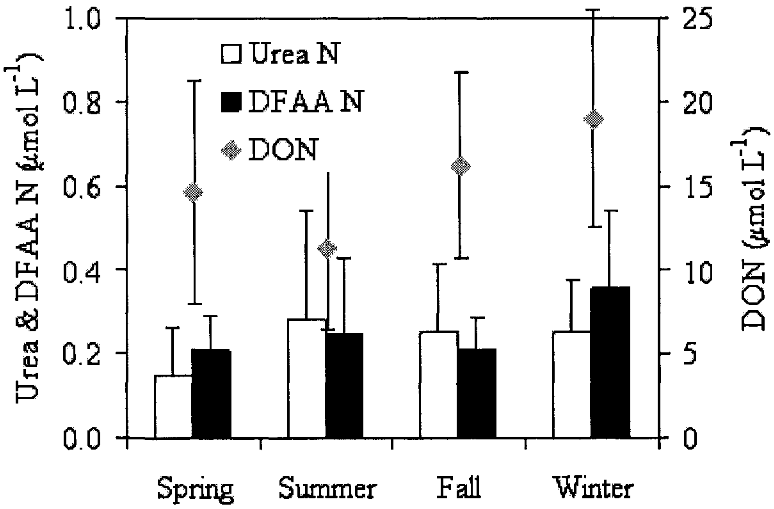

Fig. 2.15. Urea, DFAA N (left axis) and DON concentrations (right axis) averaged for each season. Error bars represent standard deviations. Urea was significantly greater in the summer compared to the spring. DFAA N was significantly greater in the winter compared to other seasons, and bulk DON concentrations were significantly lower in the summer compared to all other seasons.

When total DON, urea N, and DFAA N were averaged for all stations, there were no significant differences between stations (ANOVA; $p > 0.05$; Fig. 2.16). There were no correlations between freshwater flow, temperature, and salinity at any station to urea, DFAA N, and DON concentrations ($p > 0.05$).

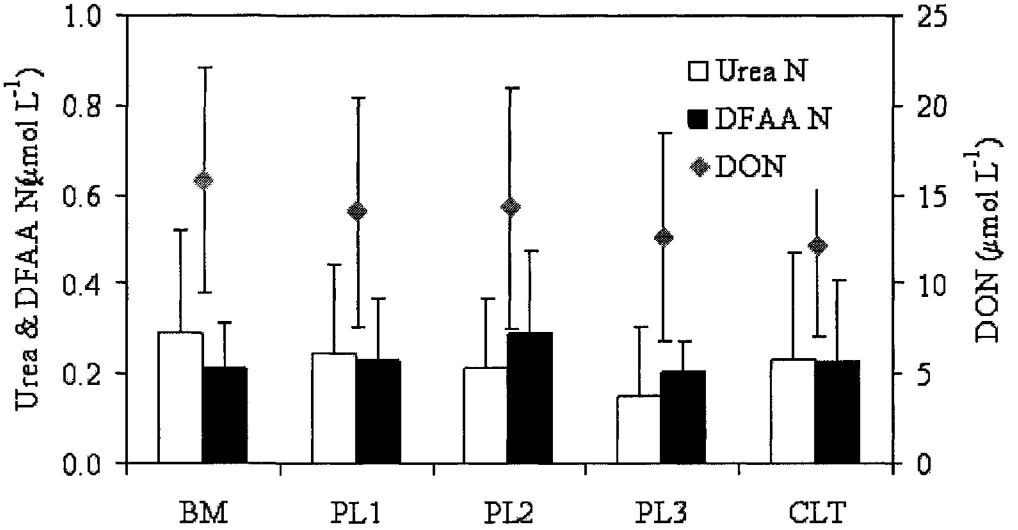

Fig 2.16. Urea, DFAA N (left axis) and DON concentrations (right axis) averaged for each station. Error bars represent standard deviations. There were no significant differences between Urea, DFAA N, or DON means among stations.

Urea N, DFAA N, and DON concentrations were averaged for each plume type, and no significant differences were observed between plume types for urea or DFAA N means (ANOVA; $p > 0.05$; Fig. 2.17). However, bulk DON means were greater during the jet-like and oceanic influenced plume types compared to the diffuse-estuarine plume type (ANOVA; Tukey test; $p < 0.05$; Fig. 2.17). When the plume was jet-like, freshwater flow, and Chl *a* had significant positive linear relationships with DON concentrations ($R = 0.425$; $R = 0.410$, respectively). There was a significant negative linear relationship between temperature and DON concentrations when the plume was jet-like ($R = -0.477$). No significant relationships were observed between urea or DFAA N concentrations and freshwater flow, temperature, salinity or Chl *a* concentrations when the plume was jet-like ($p > 0.05$). When the plume was diffuse with an estuarine, no significant linear relationships were observed between urea, DFAA N, or DON concentrations and freshwater flow, temperature, salinity, or Chl *a* concentrations ($p > 0.05$). When the plume was diffuse with an oceanic influence, only DFAA N concentrations showed a significant positive linear relationship with Chl *a* concentrations ($R = 0.546$; $p < 0.05$) and urea concentrations showed a significant positive linear relationship with temperature ($R = 0.604$; $p < 0.05$).

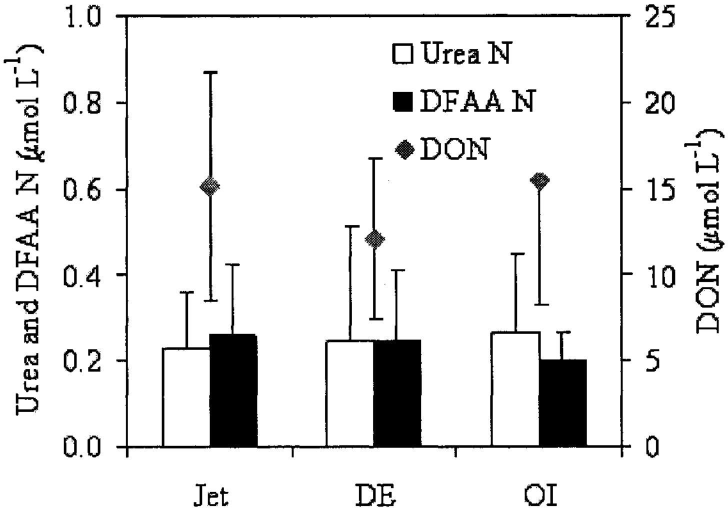

Fig 2.17. Urea, DFAA N (left axis) and DON concentrations (right axis) averaged for each plume type. Error bars represent standard deviations. There were no significant differences between Urea N or DFAA N means among plume type. Bulk DON means were significantly greater during the jet-like and oceanic influenced plume types compared to the diffuse-estuarine plume type.

BIOLOGICAL REGIME

Chl *a* concentrations were averaged at all stations and at both depths for each season, and the highest concentrations were observed during fall and winter (ANOVA, Tukey test, $p < 0.05$; Fig. 2.18). During spring, there was a significant negative linear relationship between Chl *a* concentrations and salinity (R = -0.458; Fig. 2.19) but not between Chl *a* concentrations and temperature ($p > 0.05$). No significant relationships were observed during summer between Chl *a* concentrations and salinity (Fig. 2.19) or temperature ($p > 0.05$). Temperature and salinity were negatively correlated with Chl *a* (R = -0.421, R = -0.404, respectively) in the fall months. During winter, a significant negative linear relationship was observed between Chl *a* concentrations and salinity (R = -0.673; Fig. 2.19) and a positive linear relationship was observed between Chl *a* and temperature (R = 0.570; $p < 0.05$).

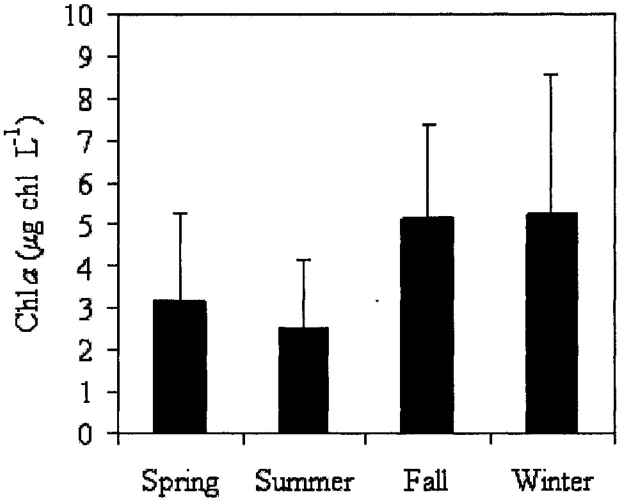

Fig. 2.18. Chl *a* concentrations averaged for each season. Error bars represent standard deviations. Fall and winter concentrations were significantly greater than spring and summer concentrations.

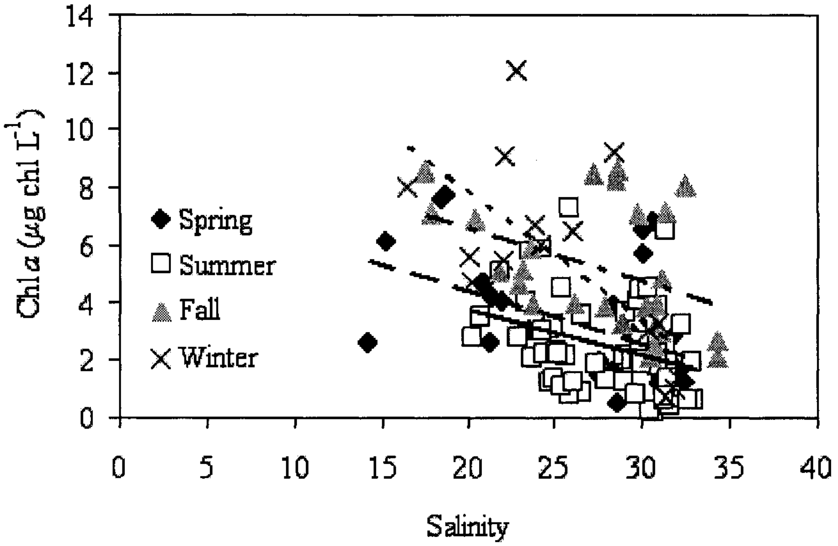

Fig. 2.19. Chl *a* concentrations versus salinity for spring, summer, fall, and winter at all stations and both depths. Significant linear relationships were observed for spring (dashed line; R = 0.458), fall (dot-dashed line; R = 0.404), and winter (small dashed line; R = 0.673) but not for summer (solid line).

Chl *a* concentrations were lowest at the CLT and PL3 stations, stations often outside the plume influence, in comparison to the BM, PL1, and PL2 stations, when averaged for all cruises at both depths (Fig. 2.20). This was different than what was observed for DIN (Fig. 2.9) where there were significant differences between the more "oceanic" CLT station and the other coastal stations. It was determined that mean concentrations at the BM, PL1, and PL2 stations were significantly greater than mean concentrations at the CLT and PL3 stations (ANOVA, Tukey test, $p < 0.05$). The CLT station was considered the more "oceanic" station therefore it was expected to have low Chl *a* concentrations. Few measurements were made at the PL3 station, so it was difficult to determine if Chl *a* concentrations were low because it was outside of the influence of the plume, or if it was anomalous due to the lack of sufficient measurements for comparisons. The BM station almost always had Chl *a* concentrations greater than those at the CLT station. There were only four instances when concentrations at the Bay mouth fell below 1.5 µg chl L^{-1}, and three were when there was an oceanic influence and one was when there was a diffuse-estuarine plume (Appendix table A.3). Chl *a* concentrations at the BM, PL1, and PL2 stations were not significantly different from each other (BM: 4.3 ± 2.2 µg chl L^{-1}; PL1: 4.3 ± 2.6 µg chl L^{-1}; PL2: 4.1 ± 2.5 µg chl L^{-1}; Fig. 2.9).

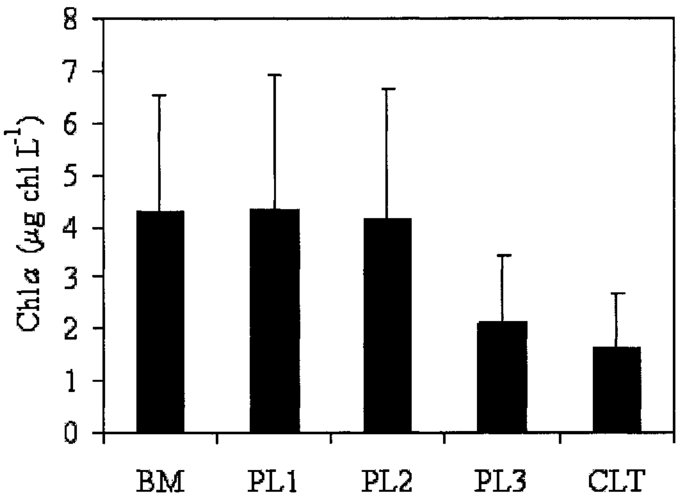

Fig. 2.20. Chl *a* concentrations averaged for all stations. Error bars are the standard deviations. Chl *a* concentrations were greatest at the BM, PL1, and PL2 stations compared to the PL3 and CLT stations.

Relationships with freshwater flow were limited to the BM station only, due to the proximity of the BM station to the James River. Salinity and temperature were used as proxies when observing relationships between freshwater flow and, biomass, nutrients, or uptake rates at other stations. A significant positive linear relationship was observed between freshwater flow and Chl *a* concentrations at the BM station for all seasons and both depths (R = 0.516; Fig. 2.21). A significant negative linear relationship was observed between salinity and Chl *a* concentrations at the BM station (R = -0.398) as well as for the pooled station data (R = -0.429; Appendix table A.6) for all seasons and both depths (Fig. 2.22). Also, a significant negative linear relationship, was observed between temperature and Chl *a* concentrations at the BM station (R = -0.452) as well as for the pooled station data (R = -0.353; Appendix table A.6) for all seasons and both depths (Fig. 2.23).

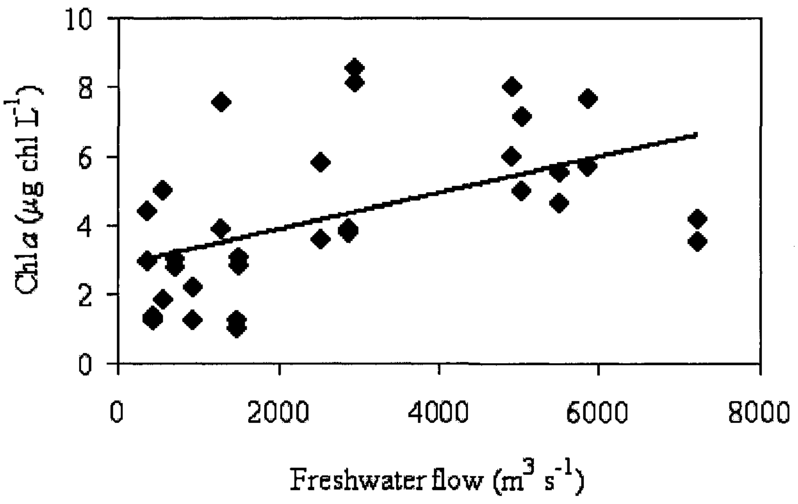

Fig. 2.21. Chl *a* concentrations versus freshwater flow for both depths at BM stations. A significant linear relationship (R = 0.516) is shown.

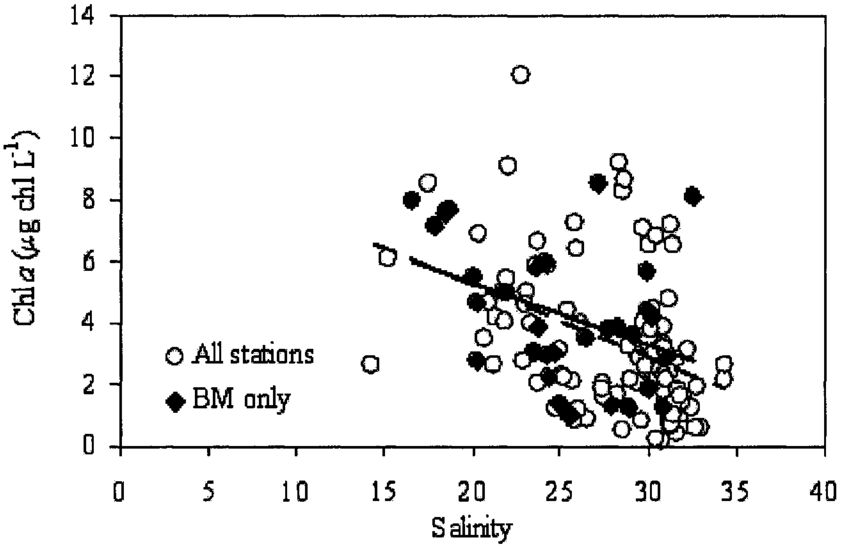

Fig. 2.22. Chl *a* concentrations versus salinity for all stations with the BM station shown separately at both depths. A significant negative linear relationship is shown for the pooled data (dashed line; R = -0.429) and for the BM station only (solid line; R = -0.398).

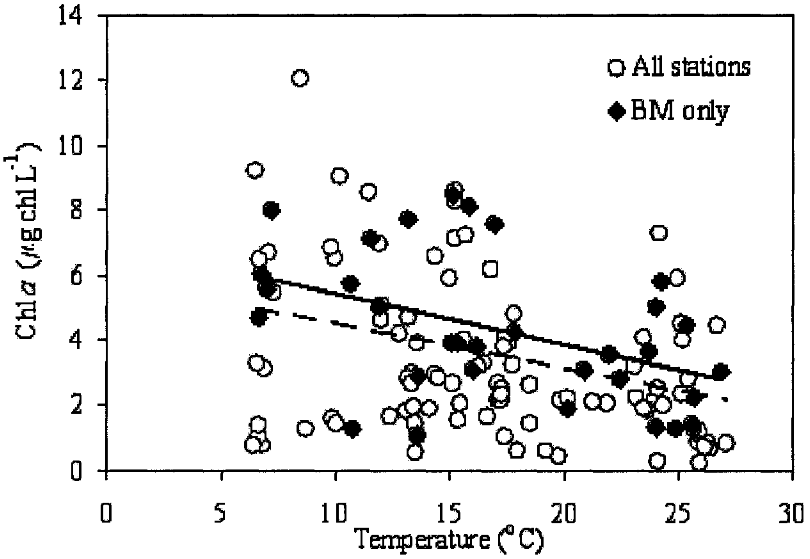

Fig. 2.23. Chl *a* concentrations versus yemperature for all stations and the BM station only at both depths. A significant negative linear relationship is shown for the pooled data (dashed line; R = -0.353) and for the BM station only (solid line; R = -0.452).

There was no significant difference between Chl *a* concentrations among plume types (ANOVA; $p > 0.05$; Fig. 2.24). The largest range of Chl *a* concentrations between stations and at both depths (0.8 – 12 μg chl L^{-1}) was observed when the plume was jet-like during March 2005 (Appendix table A.3). When the estuarine plume was diffuse, Chl *a* concentrations were less than 7.7 μg chl L^{-1}, and the oceanic influenced plume had Chl *a* concentrations less than 8.6 μg chl L^{-1} at all stations and both depths (Appendix table A.3). When the plume was jet-like, there was a significant negative linear relationship at all stations and both depths between salinity and Chl *a* ($R = -0.668$; Fig. 2.25), similar to what was found between salinity and DIN concentrations (Fig. 2.12). There was also a significant negative linear relationship but weaker correlation between temperature and Chl *a* concentrations ($R = -0.352$; $p < 0.05$). When the plume was diffusive with an estuarine influence, there was no significant relationship between salinity and Chl *a* (Fig 2.25) but there was a significant negative linear relationship between temperature and Chl *a*, and the correlation coefficient was weak ($R = -0.348$; $p < 0.05$). When there was an oceanic influence, there was no significant relationship between salinity and Chl *a* (Fig. 2.25) or between temperature and Chl *a* ($R = 0.262$; $p > 0.05$).

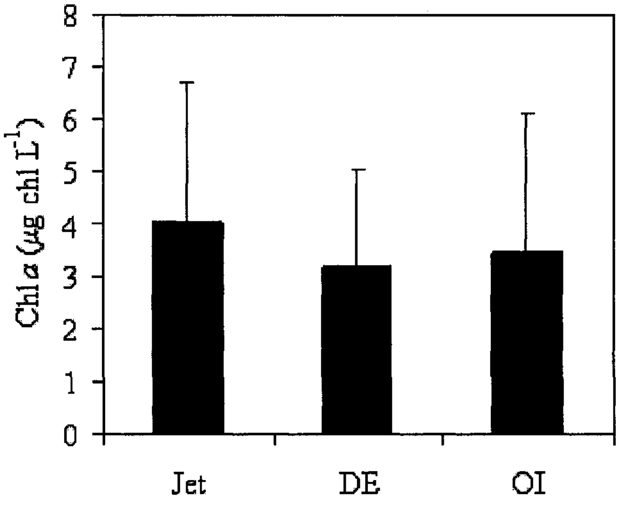

Fig. 2.24. Chl *a* concentrations averaged for each plume type. Error bars represent the standard deviations. No significant differences in mean Chl *a* concentrations were observed among plume type.

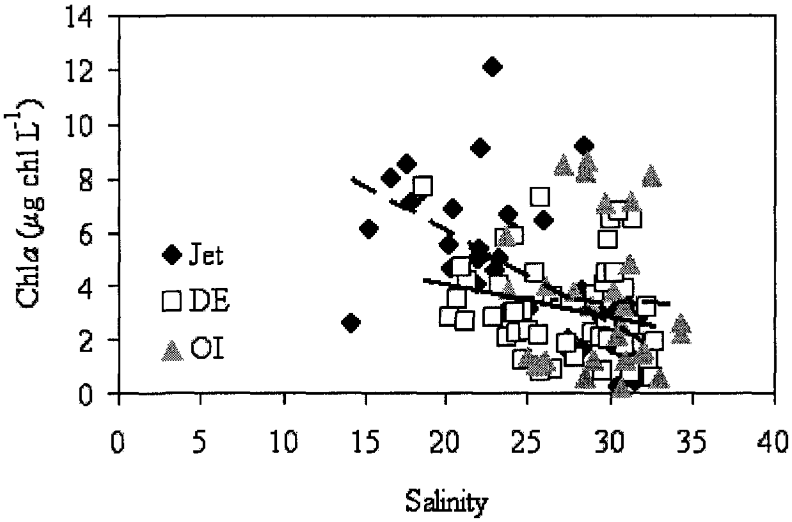

Fig. 2.25. Chl *a* concentrations versus salinity for the jet-like plume, diffuse-estuarine plume, and oceanic influenced plume. Linear regression showed a significant relationship between salinity and Chl *a* for the jet-like plume (dashed line; R = 0.668) but not for the DE (solid line) or OI (dot-dashed line) plume types.

Unlike Chl *a* results, there was no significant difference between the mean PN and PC concentrations among seasons (ANOVA; $p > 0.05$; Fig. 2.26). During spring and summer, there were significant negative linear relationships between salinity and PN concentrations (R = -0.459 and -0.595, respectively; Fig. 2.27) but not between temperature and PN or PC concentrations ($p > 0.05$). During summer, PC was negatively significantly linearly related with salinity (R = -0.464) but not during spring (Fig. 2.28). During fall, there were no significant relationships between PN or PC and salinity (Figs. 2.27 and 2.28) or temperature ($p > 0.05$). And during winter, significant negative linear relationships were observed between salinity and PN concentrations (R = -0.586; Fig. 2.27) and salinity and PC concentrations (R = 0.461; Fig. 2.28). Also, during winter, positive linear relationships were observed between temperature and PN (R = 0.506) and PC (R = 0.523).

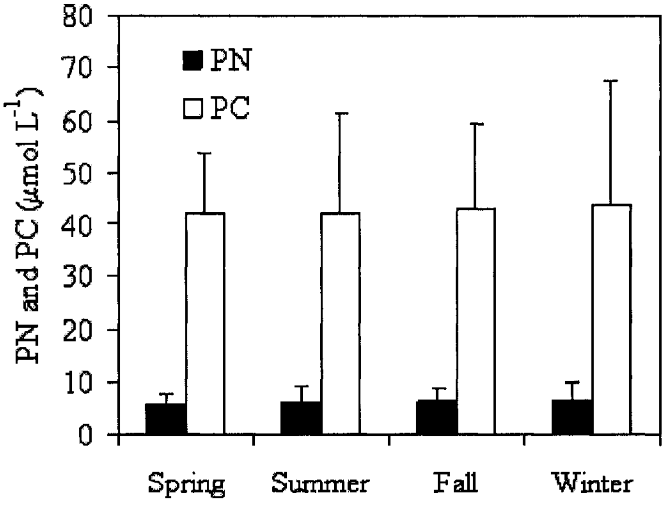

Fig. 2.26. Average PN and PC concentrations for each season. Error bars represent standard deviations. There were no significant differences among season for PN or PC concentrations.

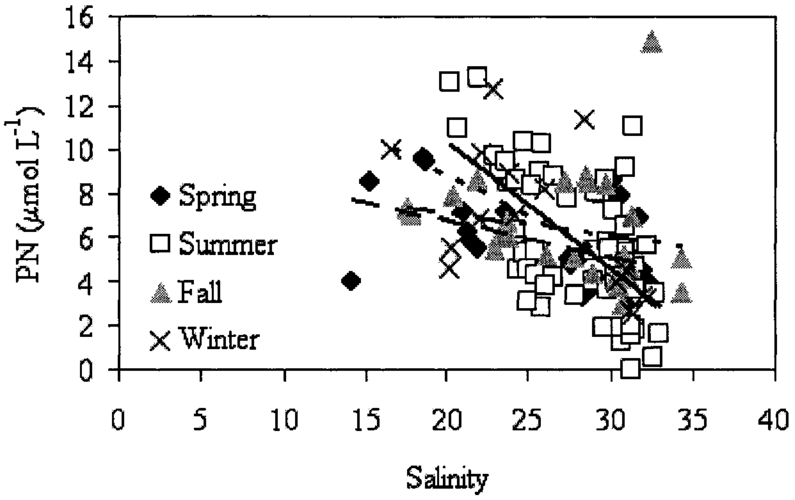

Fig. 2.27. PN concentrations versus salinity for spring, summer, fall, and winter. There were significant negative linear relationships during spring (dashed line; R = -0.459), summer (solid line; R = -0.595), and winter (small dashed line; R = -0.586), but not for fall (dot-dashed line).

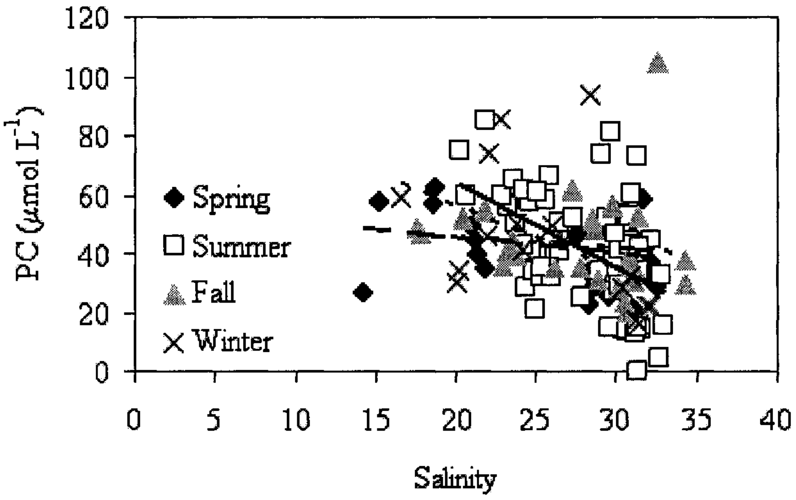

Fig. 2.28. PC concentrations versus salinity for spring, summer, fall, and winter. There were significant linear relationships during summer (solid line; R = 0.464) and winter (small dashed line; R = 0.461), but not during spring (dashed line), and fall (dot-dashed line).

Similar to Chl *a,* average PN and PC concentrations were significantly greater at the BM, PL1, and PL2 stations compared to the CLT station (ANOVA; Tukey test; $p < 0.05$; Fig. 2.29). This was different than what was observed for DIN concentrations, where there was no significant difference among stations (Fig. 2.9). The average PN concentrations at the BM station were significantly greater than the average PN concentrations at the PL3 station, however, there were fewer samples taken at the PL3 station in comparison with the other stations, therefore results should be interpreted cautiously.

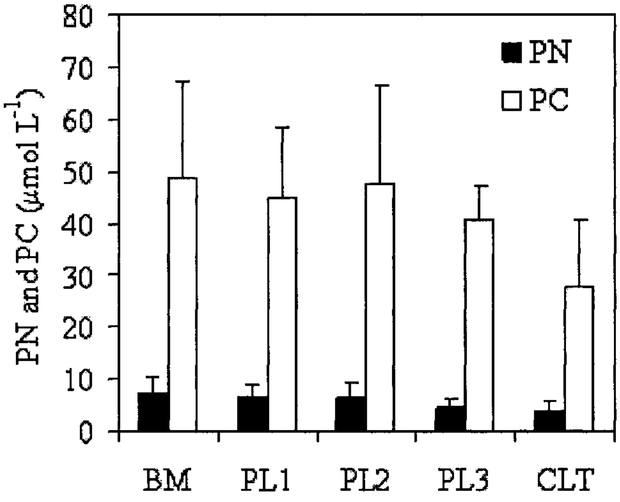

Fig. 2.29. Average PN and PC concentrations at each station. Error bars are the standard deviations. Significant differences in PN and PC concentrations were observed between the CLT station and the BM, PL1, and PL2 stations.

In contrast to Chl *a* results, PN and PC concentrations did not have a significant linear relationship with freshwater flow at the BM station (PN: $R = 0.167$; $p > 0.05$; PC: $R = 0.070$; $p > 0.05$). There was a significant negative linear relationship between salinity and PN and PC concentrations at the CLT station and when all data were pooled across seasons, stations, depths, and plume types (Figs. 2.30 and 2.31; Appendix table A.6). For each individual station and for pooled station data, no significant relationships were found between temperature and PN or PC concentrations (p > 0.05; Appendix table A.6).

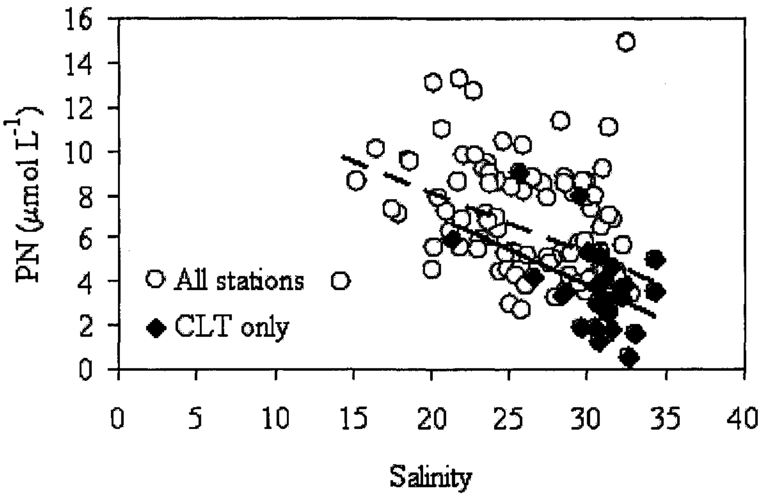

Fig. 2.30. PN concentrations versus salinity pooled for all stations and the CLT station is depicted separately at both depths. A significant negative linear relationship is shown for the pooled data (dashed line; R = -0.447) and for the CLT station only (solid line; R = -0.464).

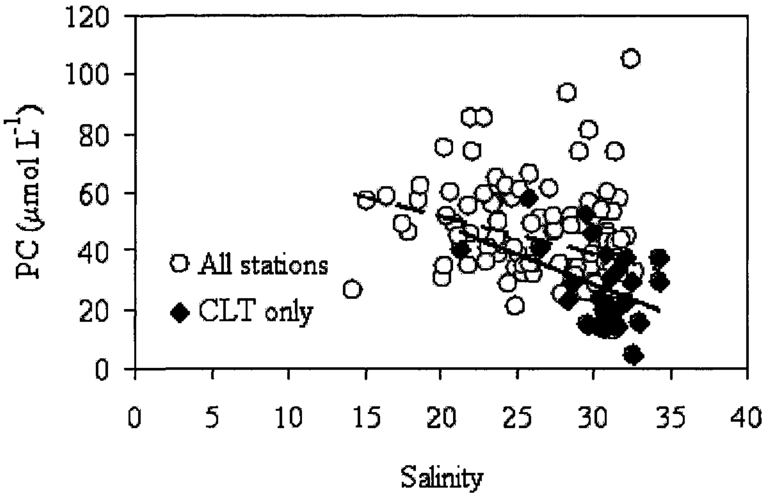

Fig. 2.31. PC concentrations versus salinity pooled for all stations and the CLT station is depicted separately at both depths. A significant negative linear relationship is shown for the pooled data (dashed line; R = -0.319) and at the CLT station only (solid line; R = -0.425).

When comparisons were made between PN and PC concentrations and plume type, it was determined that there was no significant difference in average PN and PC concentrations and plume type (ANOVA; $p > 0.05$; Fig. 2.32). However, salinity and PN or PC concentrations were significantly linearly related (Figs. 2.33 and 2.34) when the plume was jet-like or diffuse with estuarine influences. No significant relationships were found between temperature and PN or PC concentrations ($p > 0.05$) for any of the three plume types. During all three plume types, there were significant positive linear relationships between Chl *a* and PN and PC concentrations (Jet: PN R = 0.804; PC R = 0.700; DE: PN R = 0.624; PC R = 0.581; OI: PN R = 0.821; PC:R = 0.744; $p < 0.05$; Figs. 2.35 and 2.36).

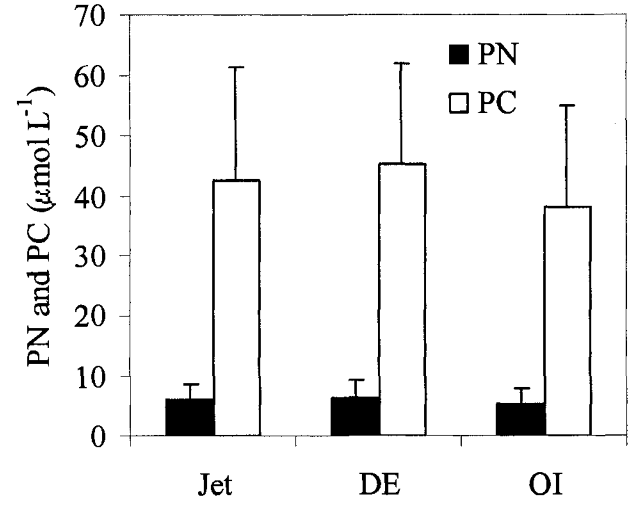

Fig. 2.32. Average PN and PC concentrations by plume type. Error bars represent the standard deviations. PN and PC concentrations during the diffuse-estuarine plume were significantly different than when there was an oceanic influence.

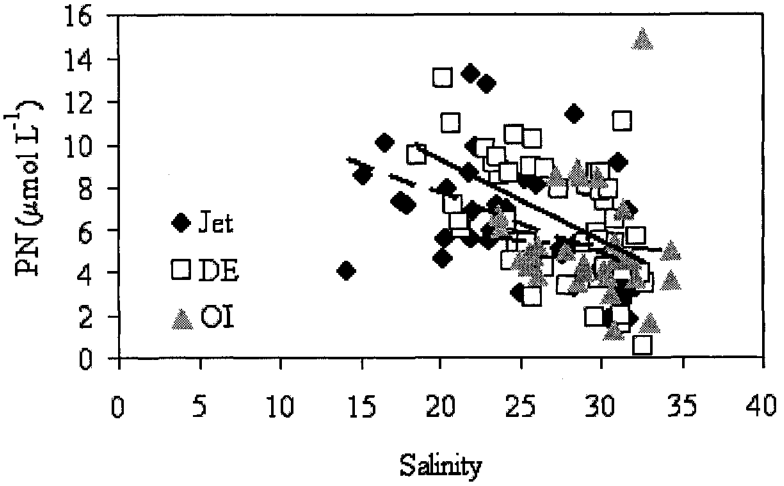

Fig. 2.33. PN concentrations versus salinity for the jet-like plume, diffuse-estuarine plume, and oceanic influenced plume. Linear regression shows a significant negative linear relationship between salinity and PN for the jet-like (dashed line; R = -0.534) and DE (solid line; R = -0.522) plume types but not for the OI (dot-dashed line) plume type.

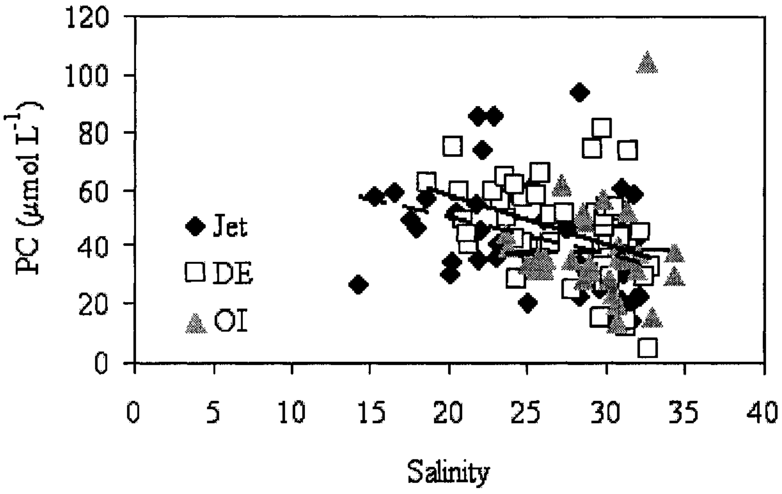

Fig. 2.34. PC concentrations versus salinity for the jet-like plume, diffuse-estuarine plume, and oceanic influenced plume. Linear regression shows a significant negative linear relationship between salinity and PC for the jet-like (dashed line; R = -0.366) and DE (solid line; R = -0.390) plume types but not for the OI (dot-dashed line) plume type.

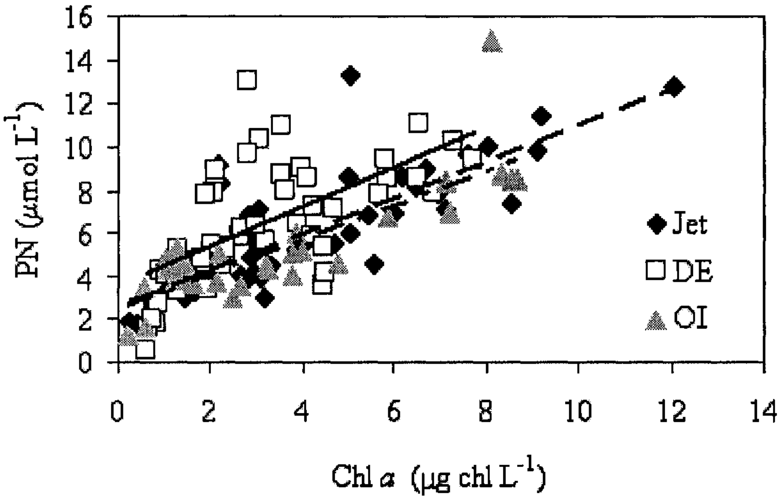

Fig. 2.35. PN concentrations versus Chl *a* concentrations for the jet-like plume, diffuse-estuarine plume, and oceanic influenced plume. Linear regression shows a significant negative linear relationship between salinity and PN for the jet-like (dashed line; R = -0.804), DE (solid line; R = -0.624) and the OI plume types (dot-dashed line; R = -0.821).

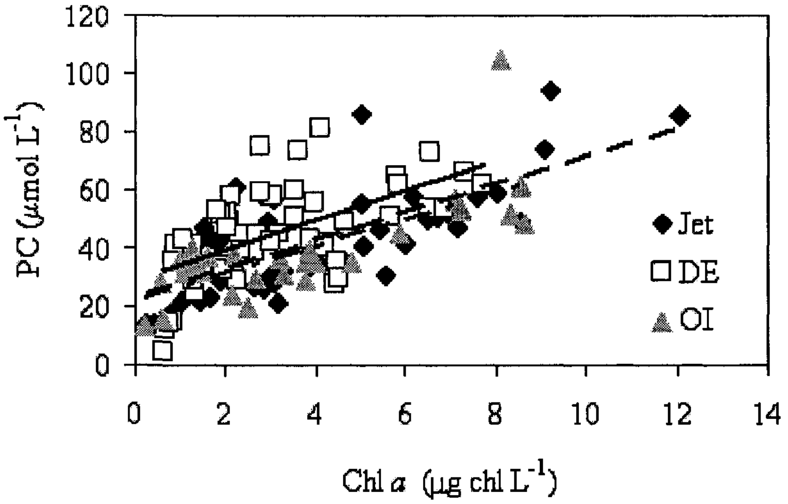

Fig. 2.36. PN concentrations versus Chl *a* concentrations for the jet-like plume, diffuse-estuarine plume, and oceanic influenced plume. Linear regression shows a significant negative linear relationship between salinity and PN for the jet-like (dashed line; R = -0.700), DE (solid line; R = -0.581) and the OI plume types (dot-dashed line; R = 0.744).

The PC to PN ratio was calculated and comparisons were made among seasons, station locations, and with respect to plume morphotypes. The average ratios were not different from (t-test) the Redfield ratio (6.6) for each season (spring = 7.6 ± 1.3; summer = 7.6 ± 1.6; fall = 6.9 ± 0.6; winter = 6.6 ± 0.7), station (BM = 6.9 ± 1.0; PL1 = 7.0 ± 1.1; PL2 = 7.4 ± 1.3; PL3 = 9.4 ± 2.0; CLT = 7.7 ± 1.2), and plume type (Jet = 7.3 ± 1.3; DE = 7.3 ± 1.5; OI = 7.5 ± 1.1).

C AND N UPTAKE

Volumetric bicarbonate uptake rates were significantly higher in the fall compared to the other seasons (ANOVA; Tukey test; $p < 0.05$; Fig. 2.37). The highest rates were observed specifically during November 2005 during downwelling-favorable conditions and an oceanic influenced hydrographic regime (Appendix table A.4).

However, when normalized to Chl *a*, primary productivity rates were significantly greater in the summer compared to the spring and winter, and rates in the fall were significantly greater than rates in the winter (ANOVA; Tukey test; $p < 0.05$; Fig. 2.37). When correlating primary productivity to Chl *a* concentrations, there was a significant positive linear relationship for the pooled data ($p < 0.05$; Fig. 2.38) but the R value was weak (0.442). When looking at individual seasons, primary productivity and Chl *a* were best correlated (positively) in the fall ($R = 0.723$; Fig. 2.39) and volumetric primary productivity rates correlated significantly ($p < 0.05$) with NO_2^- ($R = 0.753$; positive relationship), and DFAA N ($R = 0.628$; positive relationship). Similarly, during the fall, Chl *a* normalized primary productivity rates correlated significantly ($p < 0.05$) with NO_2^- ($R = 0.628$; positive relationship), and DFAA N ($R = 0.582$; positive relationship). During spring, when primary productivity rates correlated with Chl *a* but had a low R value ($R = 0.487$; Fig. 2.39), there were significant linear relationships ($p < 0.05$) between volumetric primary productivity rates and temperature ($R = 0.479$; positive relationship), salinity ($R = -0.467$), and NO_3^- concentrations ($R = 0.678$). Also during spring, Chl *a* normalized primary productivity rates correlated significantly with DON concentrations ($R = 0.435$; positive relationship) and PO_4^{3-} concentrations ($R = -0.481$). During summer, when primary productivity rates correlated with Chl *a* but had a low R value ($R = 0.475$; Fig. 2.39) volumetric primary productivity rates correlated significantly ($p < 0.05$) with salinity ($R = -0.475$), urea ($R = -0.322$), and DON ($R = 0.455$; positive relationship). Also during summer, Chl *a* normalized primary productivity rates correlated significantly with urea ($R = -0.403$), DON ($R = 0.517$). During winter, there was no significant relationship between Chl *a* and primary productivity rates, only volumetric primary productivity rates were correlated with salinity ($R = -0.605$; $p < 0.05$) and urea ($R = 0.534$; $p < 0.05$) and there were no other significant relationships between primary productivity rates and other parameters.

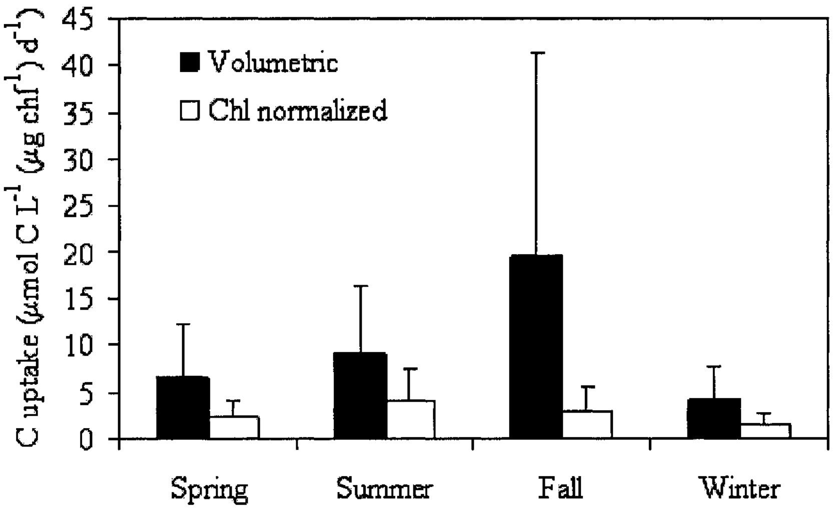

Fig. 2.37. Daily volumetric and Chl *a* normalized primary productivity rates averaged for all seasons. Error bars represent standard deviations. Fall volumetric rates were significantly higher rates during other seasons and summer Chl *a* normalized rates were significantly higher than spring and winter rates.

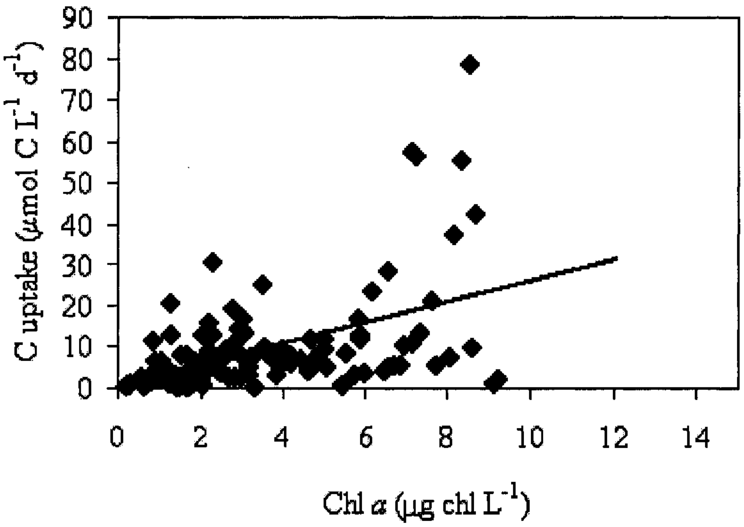

Fig. 2.38. Daily volumetric primary productivity rates versus Chl *a* concentrations for all pooled data. A significant linear relationship ($p < 0.05$) with a weak R value (0.442) is shown.

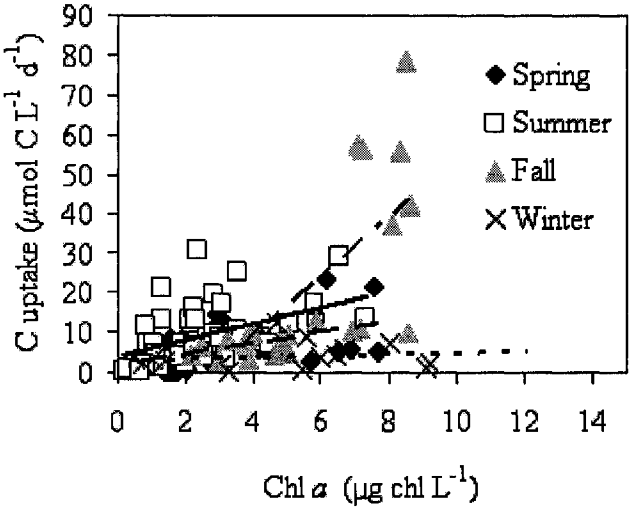

Fig. 2.39. Volumetric primary productivity rates versus Chl *a* concentrations for spring, summer, fall, and winter. A significant linear relationship was observed for spring (dashed line; R = 0.487), summer (solid line; R = 0.475), and fall (dot-dashed line; R = 0.723), but not for winter (small dashed line).

Spatially, volumetric rates, when averaged for each station, were significantly greater at the BM and PL1 stations in comparison to the CLT station (ANOVA; Tukey test; $p < 0.05$; Fig. 2.40). No significant differences were found for Chl *a* normalized primary productivity rates among stations (ANOVA; $p > 0.05$; Fig. 2.40). There were significant positive linear relationships with weak correlation coefficients between primary productivity rates and Chl *a* concentrations at the PL1 station ($R = 0.553$) and CLT station ($R = 0.481$), but no significant relationships were found at the BM, PL2, and PL3 stations (Fig. 2.41). At the BM and CLT stations, there were no significant linear relationships between freshwater flow (in the case of the BM station only), temperature, salinity or nutrients and volumetric primary productivity rates or Chl *a* normalized primary productivity rates ($p > 0.05$). At the PL1 station there were no significant relationships between temperature, or salinity and volumetric primary productivity rates or Chl *a* normalized primary productivity rates ($p > 0.05$), but there were significant relationships with Chl *a* normalized primary productivity and DFAA N ($R = 0.456$; positive relationship). Also, at the PL1 station, there was a significant linear positive relationship between volumetric primary productivity and NO_2^- concentrations ($R = 0.823$). At the PL2 station, Chl *a* normalized primary productivity correlated significantly with temperature ($R = -0.412$) but no other relationships were observed for salinity, or nutrients and primary productivity rates at the PL2 station.

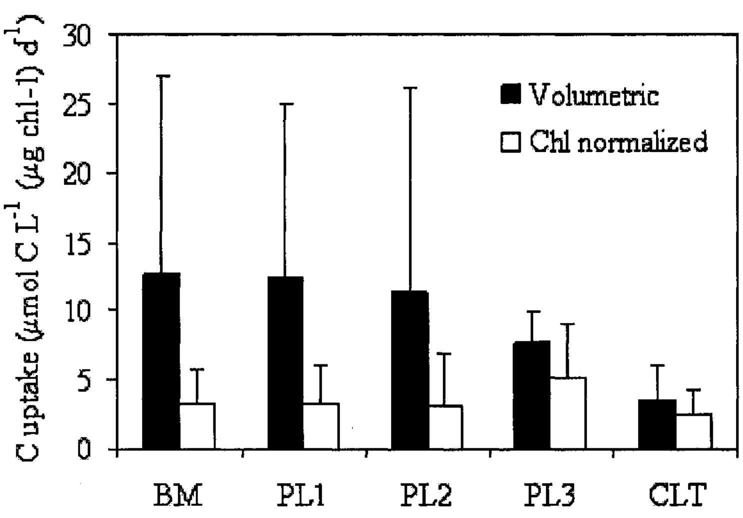

Fig. 2.40. Volumetric and Chl *a* normalized primary productivity rates averaged for each station. Error bars represent standard deviations. There was a significant difference between volumetric rates at the BM station compared to the CLT station and there was no significant differences between stations for Chl *a* normalized primary productivity rates.

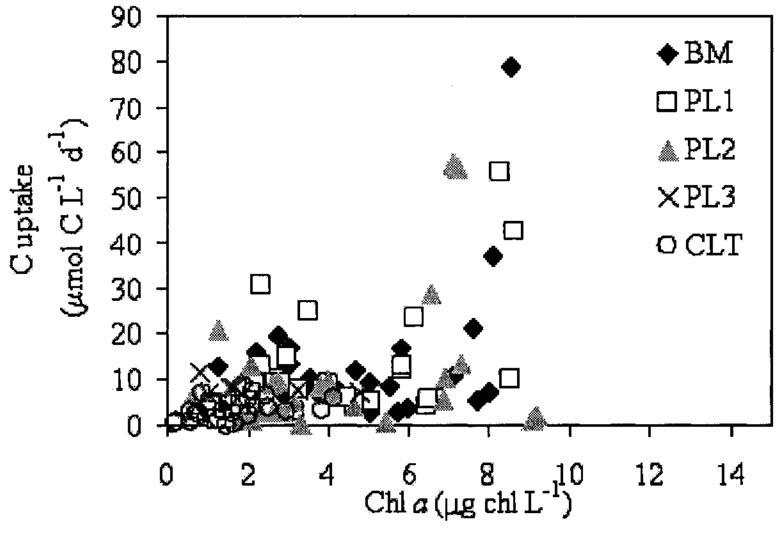

Fig. 2.41. Volumetric primary productivity rates versus Chl *a* concentrations for the BM, PL1, PL2, PL3, and CLT stations. There were no significant linear relationships observed.

The oceanic influenced plume type had significantly greater volumetric and Chl *a* normalized primary productivity rates compared to the jet-like plume type (ANOVA; Tukey test; $p < 0.05$; Fig. 2.42), and Chl *a* normalized primary productivity rates were significantly greater for the diffuse-estuarine influenced plume type compared to the jet-like plume type (ANOVA; Tukey test; $p < 0.05$; Fig. 2.42). When correlating volumetric primary productivity rates with Chl *a* concentrations for each plume type, it was determined that no significant linear relationship existed for the jet-like or diffuse-estuarine plume types ($p > 0.05$; Fig. 2.43) but there was a significant positive linear relationship during the oceanic influenced plume type ($R = 0.881$; Fig. 2.43). During the oceanic influenced plume type, volumetric primary productivity rates had significant positive linear relationships ($p < 0.05$) with PN ($R = 0.779$), PC ($R = 0.782$), NO_2^- ($R = 0.737$), DFAA N ($R = 0.637$), and SiO_4^{4-} ($R = 0.621$). When correlating volumetric primary productivity rates with salinity for each plume type, a significant negative linear relationship was observed for the jet-like plume type ($R = -0.558$), but not for the diffuse-estuarine and oceanic influenced plume types (Fig. 2.44). When correlating Chl *a* normalized primary productivity rates with salinity, no significant linear relationships were determined for each plume type ($p > 0.05$). During the diffuse-estuarine plume type, there were significant linear relationships between Chl *a* normalized primary productivity and freshwater flow ($R = -0.483$), and temperature ($R = 0.415$). During the jet-like plume type, there were no significant linear relationships between primary productivity rates (volumetric or Chl *a* normalized) and physical parameters or nutrients.

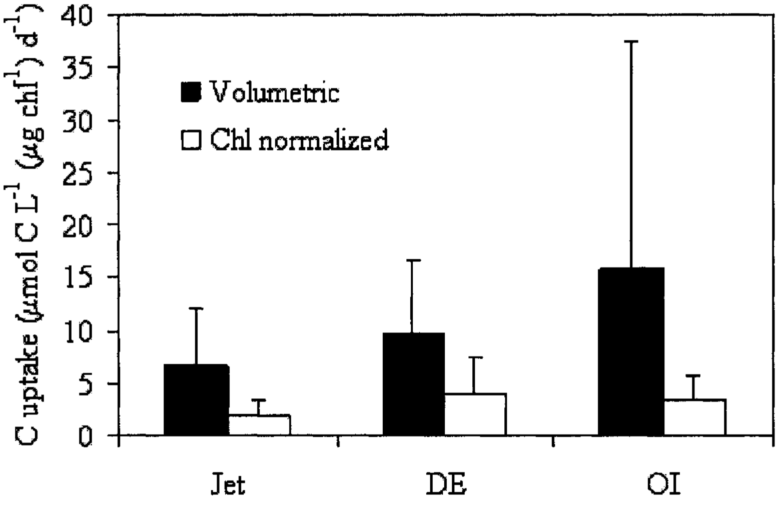

Fig. 2.42. Volumetric and Chl *a* normalized primary productivity rates averaged over plume type. Error bars represent the standard deviations. Rates were not significantly different among plume types.

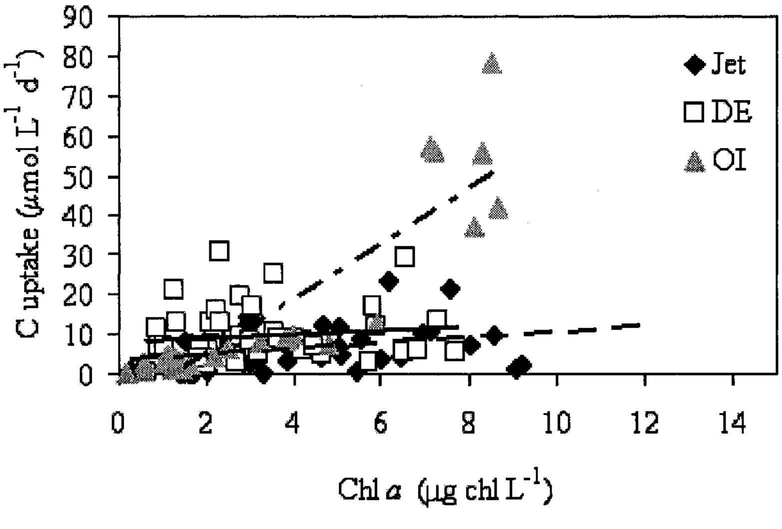

Fig. 2.43. Volumetric primary productivity rates versus Chl *a* concentrations for each plume type. Linear regression showed a significant positive relationship between volumetric primary productivity rates and Chl *a* concentrations for the OI plume type (dot-dashed line; R = 0.881) but not for the jet-like (dashed line) or DE (solid line) plume types.

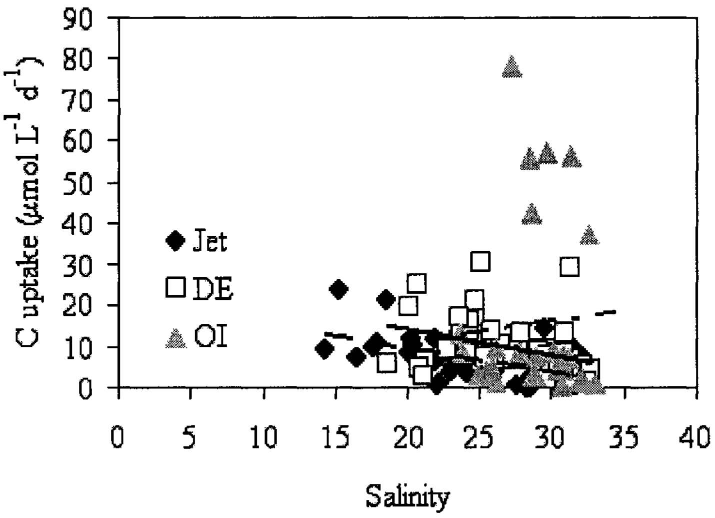

Fig. 2.44. Salinity versus volumetric primary productivity rates for the jet-like plume, diffuse-estuarine plume, and oceanic influenced plume. Linear regression showed a significant negative relationship between salinity and volumetric primary productivity rates for the jet-like plume type (dashed line; R = -0.558) but not for the jet-like (dashed line) or DE (solid line) plume types.

Volumetric rates of total N uptake ranged from 0.04 to 0.69 μmol N L^{-1} h^{-1} (Appendix table A.4). Volumetric rates did not have a significant linear correlation with Chl *a* or PN concentrations ($p > 0.05$; Appendix table A.6) for all data combined, therefore when discussing significant differences in uptake rates between seasons, stations, or plume types, volumetric uptake rates were used. When rates for each N compound were averaged for each season, total N, NH_4^+, urea N, and DFAA N uptake rates were significantly greater in the summer compared to the fall (ANOVA; Tukey test; $p < 0.05$; Table 2.45). Total N and NH_4^+ uptake rates were also greater in the summer compared to the winter, and TN uptake rates were greater in the summer compared to the spring. (ANOVA; Tukey test; $p < 0.05$; Fig. 2.45). DFAA N uptake rates were significantly greater in the summer compared to the fall (ANOVA; Tukey test; $p < 0.05$; Fig. 2.45). There were no significant differences in NO_3^- uptake rates between seasons (ANOVA; $p > 0.05$; Fig. 2.45). Overall, NH_4^+ uptake rates were highest of all individual N compound uptake rates during most of the year for all sampling years at all stations (Fig. 2.45).

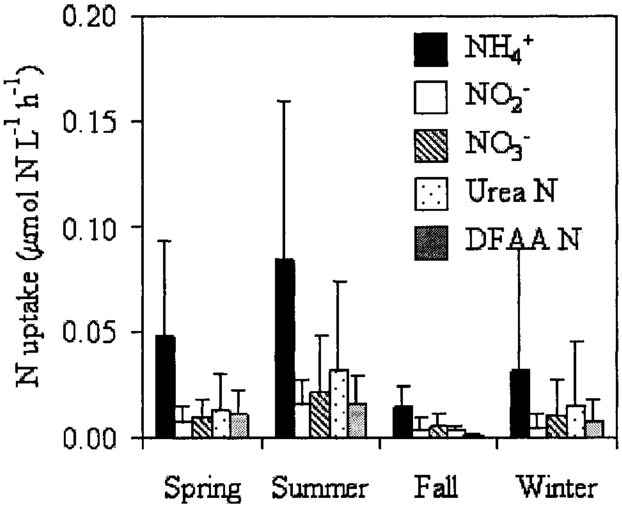

Fig. 2.45. Hourly volumetric NH_4^+, NO_2^-, NO_3^-, Urea N, and DFAA N rates averaged for all seasons. Error bars represent standard deviations. See text for significant differences.

There were no significant relationships with R values greater than 0.5 between salinity or temperature and volumetric uptake rates, or uptake rates normalized to Chl *a* for all N compounds, for all pooled data ($p > 0.05$; Appendix table A.6). There was a significant positive linear relationship between total N volumetric uptake rates and Chl *a* concentrations ($R = 0.690$; $p < 0.05$) in the fall, and this was not found for any other season.

When volumetric N uptake rates were compared between stations, there were no significant differences found between total N uptake rates or individual N compound uptake rates and station location (ANOVA; $p > 0.05$; Fig. 2.46). No significant relationships were observed at the BM station between individual volumetric N uptake rates and freshwater flow or salinity ($p > 0.05$). However, total N and NH_4^+ volumetric uptake rates were correlated positively with temperature at the BM station, with R values less than 0.5 (TN: $R = 0.496$; $p < 0.05$; NH_4^+: $R = 0.440$; $p < 0.05$). A significant negative linear relationship was found between freshwater flow and total N uptake rates normalized to Chl *a* ($R = -0.594$; $p < 0.05$; Fig. 2.47) and a significant positive linear relationship was found between temperature and NH_4^+ uptake rates normalized to Chl *a* at the BM station ($R = 0.448$; $p < 0.05$; Fig. 2.48). At the CLT station, there were no significant relationships between volumetric N uptake rates or N uptake rates normalized to Chl *a* and salinity or temperature ($p > 0.05$). At the PL1 station, no significant relationships were observed between volumetric N uptake rates or N uptake rates normalized to Chl *a* and salinity ($p > 0.05$). However, there were significant positive linear relationships between temperature and total N uptake rates ($R = 0.435$) and total N uptake rates normalized to Chl *a* at the PL1 station ($R = 0.473$). At the PL2 station, no significant relationships were observed with volumetric N uptake rates or Chl *a* normalized uptake rates and salinity ($p > 0.05$), however, there was a significant positive linear relationship between temperature and total N uptake rates normalized to Chl *a* with an R value less than 0.5 ($R = 0.435$, $p < 0.05$). Uptake rate measurements were made at the PL3 station only 8 times and statistical analyses could not be interpreted with much confidence.

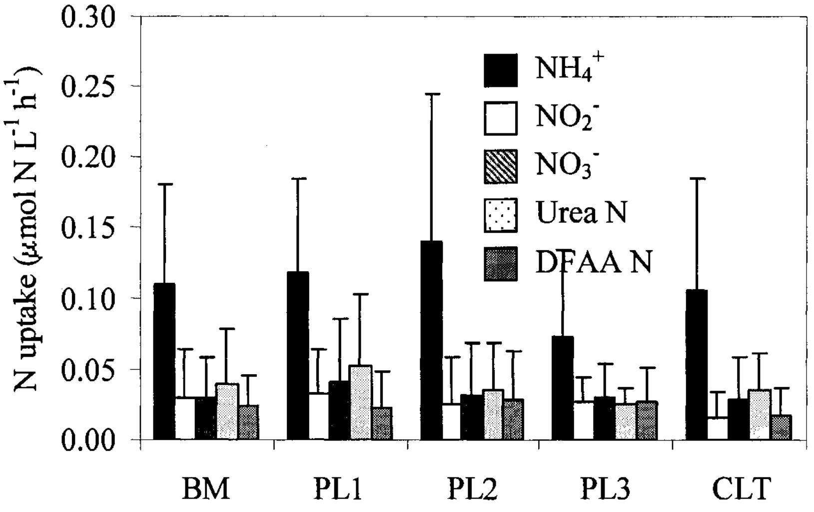

Fig. 2.46. Hourly volumetric NH_4^+, NO_2^-, NO_3^-, Urea N, and DFAA N rates averaged for each station. Error bars represent standard deviations. There were no significant differences between volumetric rates at any station.

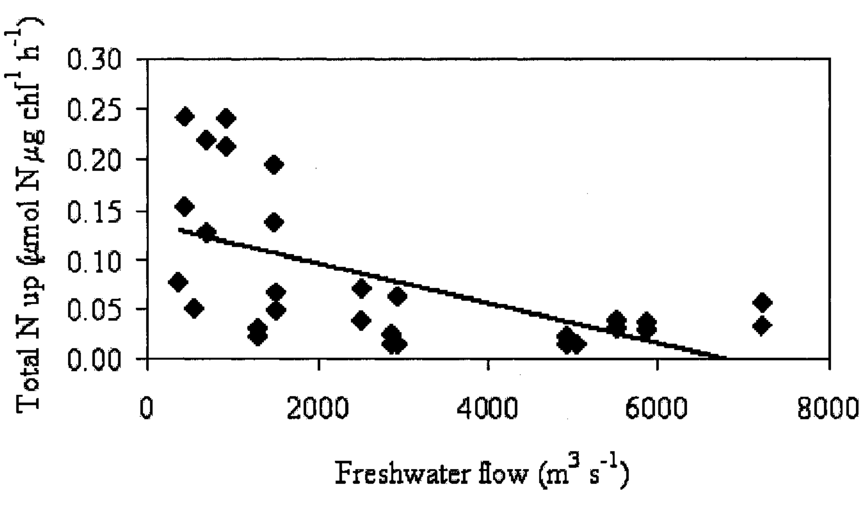

Fig. 2.47. Freshwater flow versus total N uptake rates normalized to Chl *a* at the BM station for all seasons and all depths. A significant linear relationship is shown (R = 0.594).

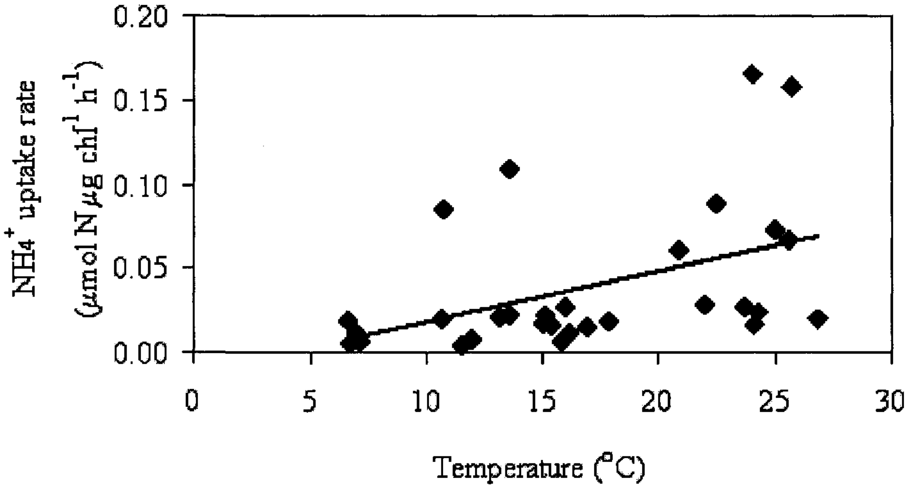

Fig. 2.48. Temperature versus NH_4^+ uptake rates normalized to Chl *a* at the BM station for all seasons and all depths. A significant linear relationship is shown (R = 0.448).

There were significant differences when averaging volumetric N uptake rates over each plume type (Fig. 2.49). NH_4^+ volumetric uptake rates were significantly greater when the plume was diffuse with an estuarine influence compared to when the plume was jet-like or had an oceanic influence (ANOVA; Tukey test; $p < 0.05$; Fig. 2.49). NO_2^- volumetric uptake rates were significantly greater when the plume was diffuse with an estuarine influence compared to when the plume was jet-like (ANOVA; Tukey test; $p < 0.05$; Fig. 2.49). DFAA N volumetric uptake rates were significantly greater when the plume was diffuse with an estuarine influence compared to when there was an oceanic influence (ANOVA; Tukey test; $p < 0.05$; Fig. 2.49). There were no significant differences between NO_3^- and Urea N volumetric uptake rates amongst plume types (ANOVA; $p > 0.05$; Fig. 2.49). The diffuse-estuarine plume type had the greatest total N uptake rates compared to the jet-like plume and the oceanic influenced plume type

(ANOVA; Tukey test; $p < 0.05$). At all plume types, NH_4^+ was the dominant N compound being taken up (Fig. 2.49).

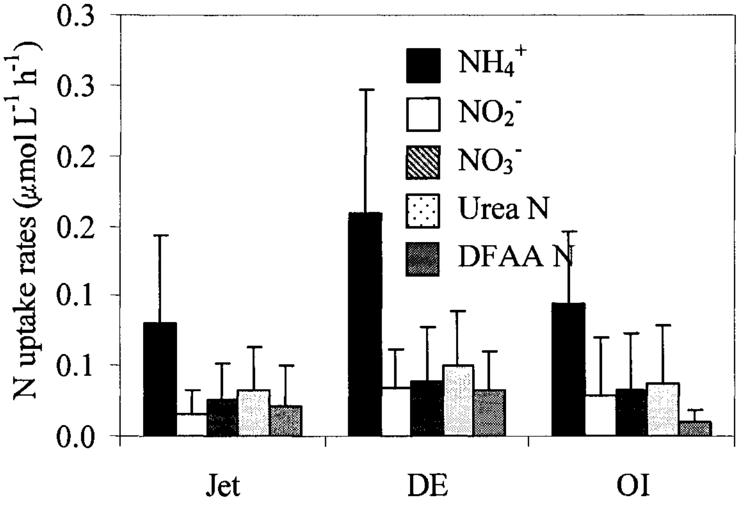

Fig. 2.49. Volumetric N uptake rates averaged over plume type. Error bars represent the standard deviations. Rates were significantly different for NH_4^+ uptake rates during the diffuse-estuarine plume type compared to the jet-like and oceanic influenced plume types, for NO_2^- uptake rates during the diffuse-estuarine plume type compared to the jet-like plume type, and for DFAA N uptake rates during the diffuse-estuarine plume type and the oceanic influenced plume type.

When the plume was jet-like, no significant relationships were observed for N uptake rates (volumetric or Chl *a* normalized) and salinity, or temperature ($p > 0.05$). When the plume was diffuse with an estuarine influence, there was a weak significant negative linear relationship between total N volumetric uptake rates and salinity ($R = -0.453$; $p < 0.05$) and in particular between NO_2^- ($R = -0.469$; $p < 0.05$), urea N ($R = -0.614$; $p < 0.05$), and DFAA N ($R = -0.557$; $p < 0.05$) volumetric uptake rates and salinity. There were also weak significant positive linear relationships between temperature and total N uptake rates normalized to Chl *a* ($R = 0.445$; $p < 0.05$), NO_2^- uptake rates normalized to Chl *a* ($R = 0.441$; $p < 0.05$), Urea N uptake rates normalized to Chl *a* ($R = 0.467$; $p < 0.05$), and DFAA N uptake rates normalized to Chl *a* ($R = 0.476$; $p < 0.05$) when the plume was diffuse with an estuarine influence. When there was an oceanic influence, volumetric N uptake rates were not significantly correlated with salinity or temperature, except for urea N volumetric uptake rates, which had a significant positive linear relationship with temperature ($R = 0.698$; $p < 0.05$). Total N uptake rates normalized to Chl *a* did not have a significant relationship with salinity, but did have a weak significant positive linear relationship with temperature when there was an oceanic influence ($R = 0.478$; $p < 0.05$). In particular, NO_2^- ($R = 0.521$; $p < 0.05$), NO_3^- ($R = 0.441$; $p < 0.05$), and urea N ($R = 0.662$; $p < 0.05$) uptake rates normalized to Chl *a* had significant positive linear relationships with temperature.

Volumetric NH_4^+ uptake rates, NH_4^+ uptake rates normalized to PN concentrations, and Chl *a* normalized NH_4^+ uptake rates were not significantly correlated with NH_4^+ concentrations for all pooled data ($p > 0.05$; Appendix table A.6). However, when observing NH_4^+ concentrations less than 1.2 μmol L^{-1}, there was a significant linear relationship observed between NH_4^+ concentrations and NH_4^+ volumetric uptake rates ($R = 0.525$), and a significant linear relationship but lower R value (0.343) observed between NH_4^+ concentrations and NH_4^+ uptake rates normalized to PN concentrations (Fig. 2.50). No relationship was observed between NH_4^+ concentrations less than 1.2 μmol L^{-1} and NH_4^+ uptake rates normalized to Chl *a* (Fig. 2.50). NH_4^+ concentrations were not correlated with volumetric NH_4^+ uptake rates, or NH_4^+ uptake rates normalized to Chl *a* or PN concentrations at any station location or for all three plume types ($p > 0.05$).

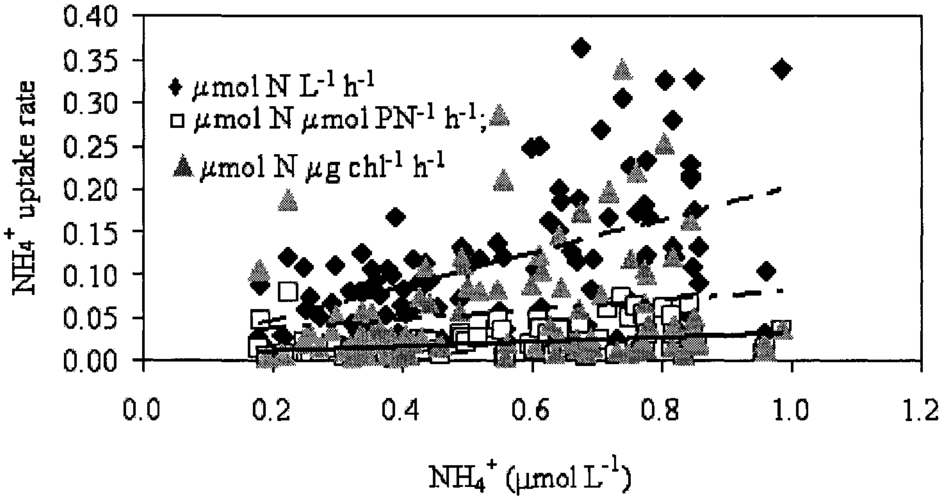

Fig. 2.50. NH_4^+ uptake rates versus NH_4^+ concentrations less than 1.2 µmol L^{-1} for all pooled data. Significant linear relationships were found for volumetric uptake rates (dashed line; R = 0.525) and uptake rates normalized to PN concentrations (solid line: R = 0.343) but not for uptake rates normalized to chl *a* (dot-dashed line).

Uptake rates for NO_2^- were correlated with NO_2^- concentrations for all pooled data (Appendix table A.6) and a significant positive linear relationship was found for volumetric uptake rates ($R = 0.568$; $p < 0.05$; Fig. 2.51) and NO_2^- concentrations and uptake rates normalized to PN concentrations ($R = 0.420$; $p < 0.05$; Fig. 2.51) but not when normalized to Chl *a* concentrations ($p > 0.05$; Fig. 2.52) Fig. 2.51). Although Fig. 2.51 appeared to show that at NO_2^- concentrations less than 0.2 µmol L^{-1} there may have been a stronger linear relationship with uptake rates, the R values were lower for both volumetric uptake rates ($R = 0.302$; $p < 0.05$) and rates normalized to PN ($R = 0.382$; $p < 0.05$) at concentrations less than 0.2 µmol L^{-1}, even though the relationships were significant. When observing the relationship between NO_2^- concentrations and NO_2^- uptake rates on a seasonal basis, a significant positive linear relationship was observed during the fall months between NO_2^- concentrations (when NO_2^- concentrations were as high as 1.86 μmol L^{-1}) and NO_2^- volumetric uptake rates ($R = 0.820$; $p < 0.05$; Fig. 2.52), rates normalized to PN ($R = 0.793$; $p < 0.05$; Fig. 2.52), and rates normalized to Chl *a* concentrations ($R = 0.756$; $p < 0.05$; Fig. 2.52). No significant relationships were observed between NO_2^- concentrations and NO_2^- uptake rates for spring, summer, or winter ($p > 0.05$). NO_2^- volumetric uptake rates were correlated positively with NO_2^- concentrations at all stations (BM: $R = 0.639$; PL1: $R = 0.633$; PL2: $R = 0.447$; $p < 0.05$) except for the CLT and PL3 ($p > 0.05$), where NO_2^- concentrations were less than 0.2 μmol L^{-1}. NO_2^- concentrations did not have a significant linear relationship with NO_2^- uptake rates normalized to PN or Chl *a* at any station ($p > 0.05$). When observing the relationship between NO_2^- concentrations and NO_2^- uptake rates for all three plume types, significant linear relationships were found during the oceanic influenced plume type, particularly between NO_2^- concentrations and volumetric uptake rates ($R = 0.765$; $p < 0.05$; Fig. 2.53) and rates normalized to PN ($R = 0.585$; $p < 0.05$; Fig. 2.53). No significant relationships were observed between NO_2^- concentrations and NO_2^- uptake rates for the diffuse-estuarine plume or the jet-like plume ($p > 0.05$).

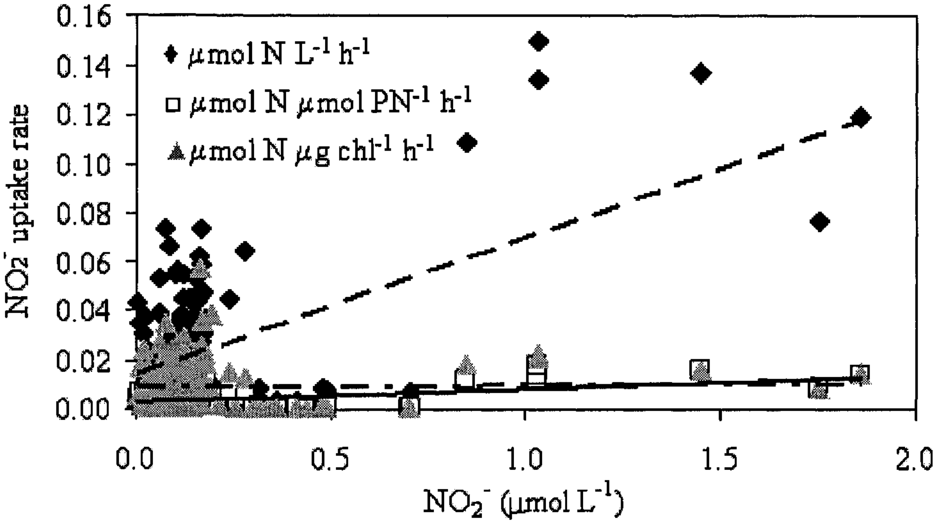

Figure 2.51. NO_2^- uptake rates versus NO_2^- concentrations for pooled data. Significant linear relationships were found for volumetric uptake rates (dashed line; R = 0.568) and rates normalized to PN concentrations (solid line; R = 0.420) but not for uptake rates normalized to chl *a* (dot-dashed line).

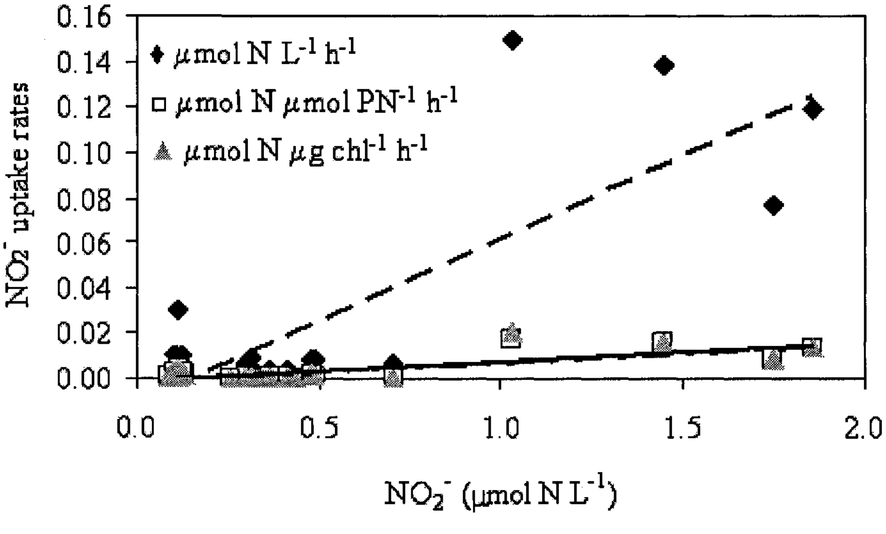

Fig. 2.52. NO_2^- uptake rates versus NO_2^- concentrations for fall months. Significant positive linear relationships were found for volumetric uptake rates (dashed line; R = 0.737), uptake rates normalized to PN (solid line; R = 0.549), and uptake rates normalized to Chl *a* concentrations (dot-dashed line; R = 0.703).

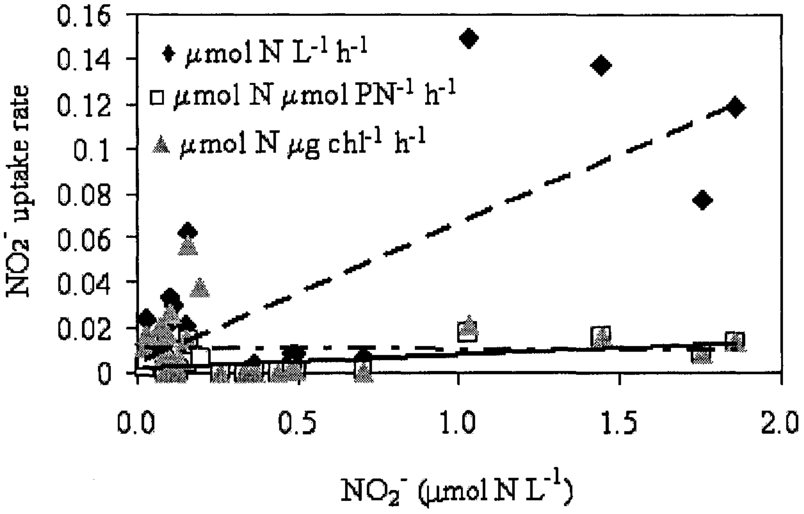

Figure 2.53. NO_2^- uptake rates versus NO_2^- concentrations for the oceanic influenced plume type. Significant linear relationships were found for volumetric rates (dashed line; $R = 0.765$) and rates normalized to PN concentrations (solid line; $R = 0.585$) but not for uptake rates normalized to chl *a* (dot-dashed line).

NO_3^- uptake rates were correlated with NO_3^- concentrations and no significant relationships were observed for all pooled data ($p > 0.05$; Fig. 2.54; Appendix table A.6). On closer inspection of individual seasons however, it was found that there were significant positive linear relationships between NO_3^- concentrations and NO_3^- uptake rates for spring and summer months (Figs. 2.55 and 2.56). For the spring, when concentrations were as high as 2.5 μmol L^{-1}, significant relationships were found between NO_3^- concentrations and volumetric NO_3^- uptake rates ($R = 0.752$; $p < 0.05$; Fig. 2.55) and NO_3^- uptake rates normalized to PN concentrations ($R = 0.553$; $p < 0.05$; Fig. 2.55), but the relationships appeared to be skewed by the higher NO_3^- concentrations. For the summer, when concentrations were as high as 0.7 μmol L^{-1}, significant relationships were found between NO_3^- concentrations and volumetric NO_3^- uptake rates ($R = 0.452$; $p < 0.05$; Fig. 2.56), NO_3^- uptake rates normalized to PN ($R = 0.490$; $p < 0.05$; Fig. 2.56), and NO_3^- uptake rates normalized to Chl *a* concentrations ($R = 0.431$; $p < 0.05$; Fig. 2.56). Regarding station location and plume types, no significant relationships were observed between NO_3^- concentrations and NO_3^- uptake rates for individual stations or plume types ($p > 0.05$).

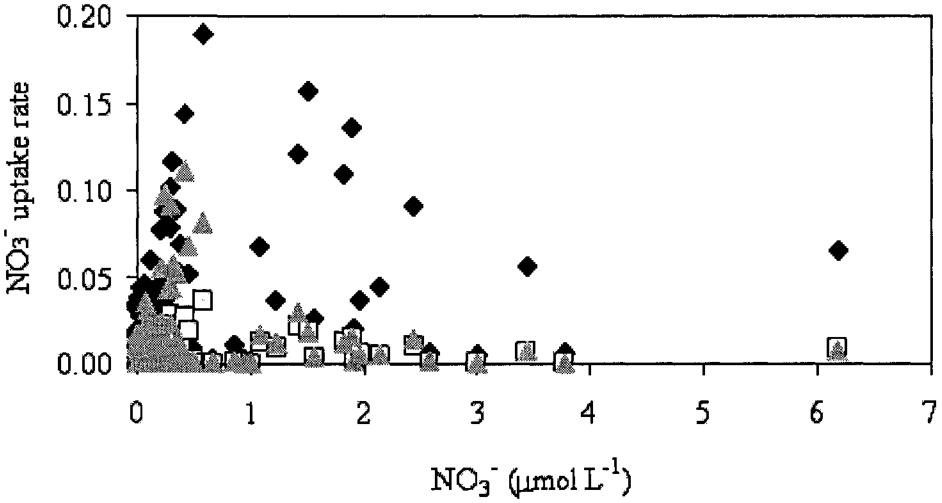

Fig 2.54. NO_3^- uptake rates versus NO_3^- concentrations for all pooled data. No significant linear relationships were found.

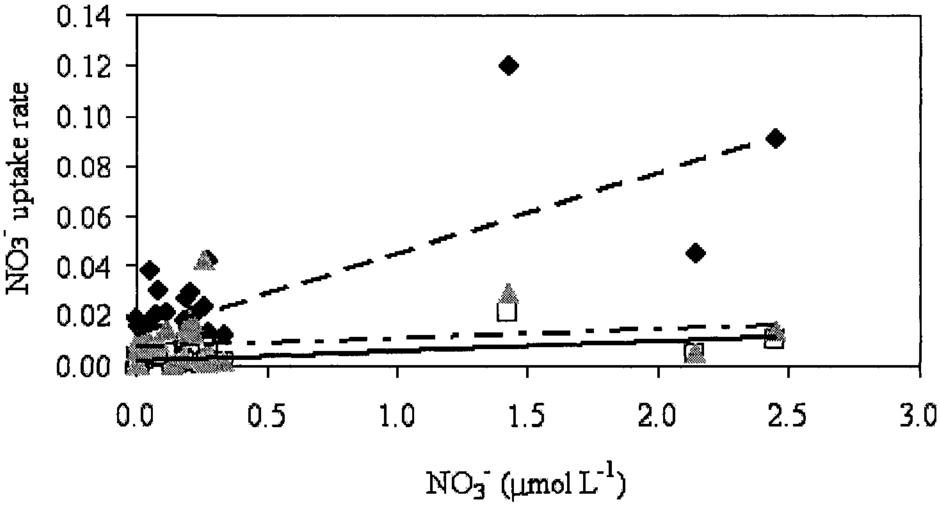

Figure 2.55. NO_3^- uptake rates versus NO_3^- concentrations for the spring. Significant linear relationships were found between NO_3^- concentrations and volumetric NO_3^- uptake rates (dashed line; R = 0.752) and NO_3^- uptake rates normalized to PN concentrations (solid line; R = 0.553) but not for uptake rates normalized to chl *a* (dot-dashed line).

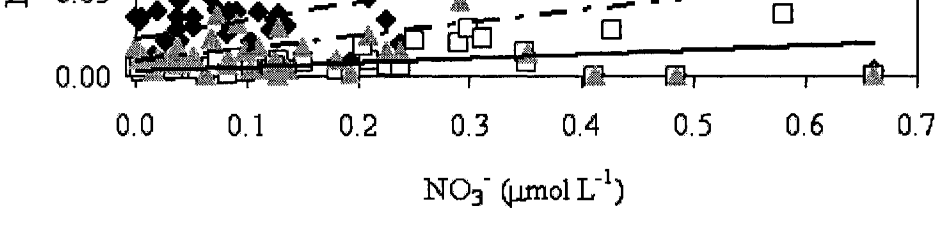

Fig. 2.56. NO_3^- uptake rates versus NO_3^- concentrations for the summer. Significant linear relationships were found between NO_3^- concentrations and volumetric NO_3^- uptake rates (dashed line; R = 0.452), NO_3^- uptake rates normalized to PN (solid line; R = 0.490), and NO_3^- uptake rates normalized to Chl *a* concentrations (dot-dashed line; R = 0.431).

Similar to NO_3^- uptake rates, urea concentrations were not correlated with urea uptake rates for all pooled data ($p > 0.05$; Fig. 2.57; Appendix table A.6). No significant relationships were found during individual seasons, at individual station locations, or for individual plume types. Urea uptake rates were not reliant on urea concentrations during any time. Overall, volumetric urea uptake rates, and urea uptake rates normalized to Chl *a* weakly correlated with temperature ($R = 0.332$, 0.335, respectively; $p < 0.05$).

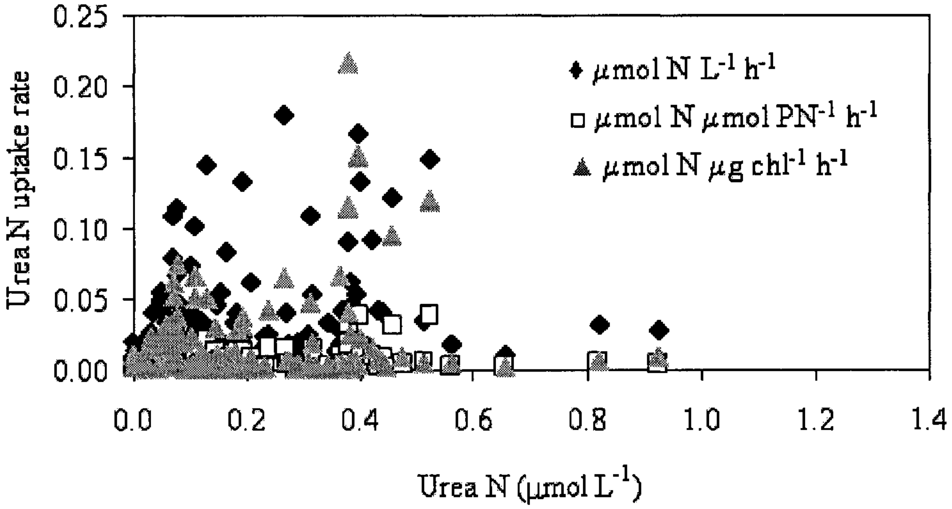

Fig. 2.57. Urea N uptake rates versus urea N concentrations for all pooled data. No significant linear relationships were found.

DFAA N concentrations had significant relationships but weak correlations with DFAA N uptake rates for all pooled data (Fig. 2.58; Appendix table A.6). On a seasonal basis, significant positive linear relationships were observed during the summer between DFAA N concentrations and DFAA N uptake rates normalized to Chl *a* ($R = 0.507$; $p < 0.05$) and DFAA N uptake rates normalized to PN concentrations ($R = 0.680$; $p < 0.05$). Significant positive linear relationships at individual station locations were only observed at the CLT between DFAA N concentrations and DFAA N uptake rates normalized to Chl *a* (R = 0.580; $p < 0.05$) and DFAA N uptake rates normalized to PN concentrations (R = 0.666; $p < 0.05$). There were no significant relationships between DFAA N concentrations and DFAA N uptake rates for individual plume types.

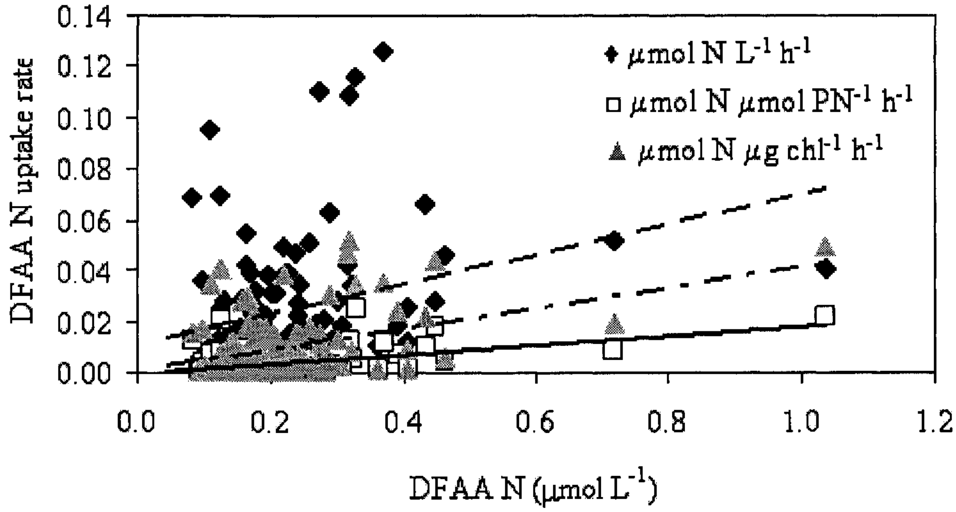

Fig. 2.58. DFAA N uptake rates versus DFAA N concentrations for all pooled data. Significant linear relationships were found for volumetric uptake rates (dashed line; R = 0.284), uptake rates normalized to PN (solid line; R = 0.475), and rates normalized to Chl *a* (dot-dashed line; R = 0.416).

C to N uptake ratios were calculated by dividing hourly bicarbonate uptake by hourly total N uptake, as C uptake by DFAA's and urea were a negligible percent (on average < 5%) of C uptake compared to inorganic C uptake. Hourly C to N uptake ratios were averaged for each season (Fig. 2.59). Fall uptake ratios were significantly greater than ratios during the spring, summer, and winter and averaged below the Redfield ratio (6.6) (Fall: 4.6 ± 2.4) (ANOVA; Tukey test; $p < 0.05$; Fig. 2.59). When ratios were averaged for each station, the BM station was found to have significantly greater C:N uptake ratios than at the CLT station (ANOVA; Tukey test; $p < 0.05$; Fig. 2.60). Ratios at the BM were much lower than the Redfield ratio, with an average and standard deviation of 3.5 ± 2.7. When ratios were averaged for each plume type, the oceanic-influenced and jet-like plume types were found to have significantly greater C:N uptake ratios compared to the diffuse-estuarine plume type (ANOVA; Tukey test; $p < 0.05$; Fig. 2.61). The average ratio during the oceanic influenced scenario was 3.5 ± 3.0, and during the jet-like it was 2.7 ± 2.1, lower than the canonical Redfield ratio.

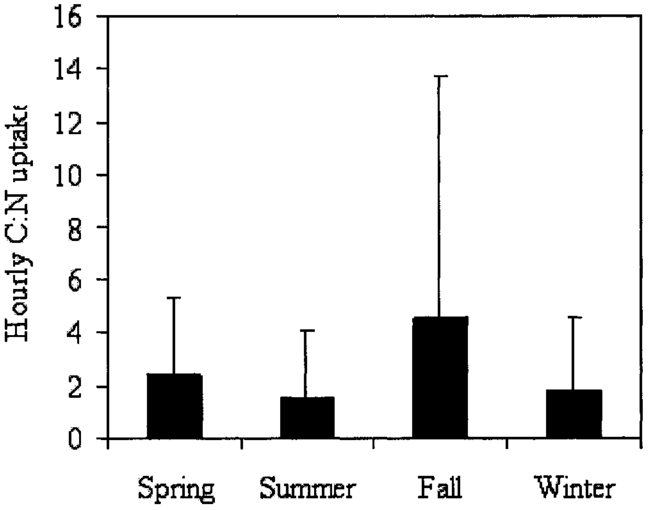

Fig. 2.59. Seasonally averaged C to N uptake ratios based on hourly uptake rates. Ratios in the fall were significantly greater than ratios in the spring, summer, and winter.

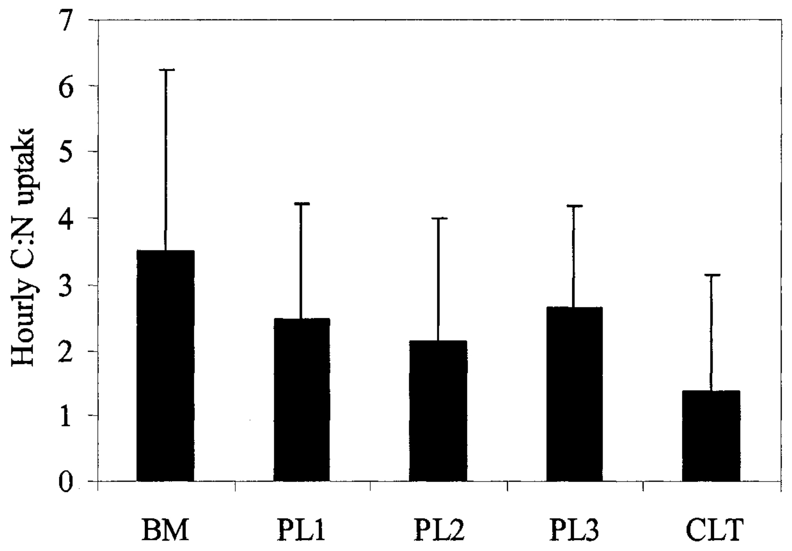

Fig. 2.60. C to N uptake ratios averaged over for each station. Ratios at the BM station were significantly greater than ratios at the CLT station.

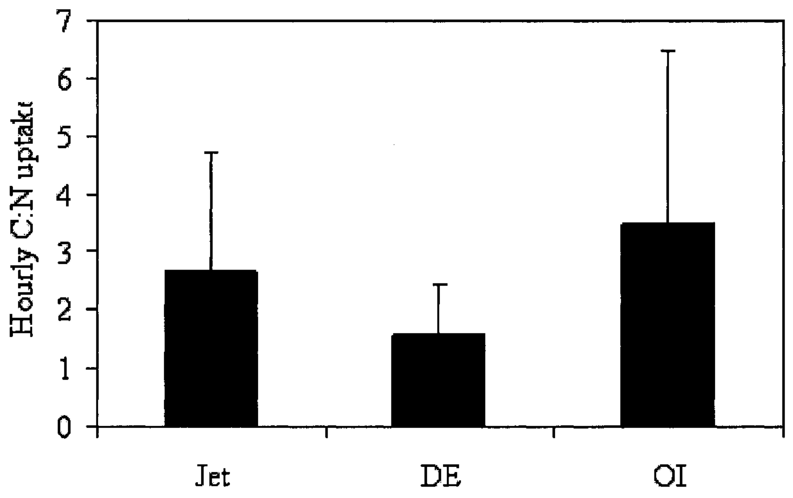

Fig. 2.61. C to N uptake ratios averaged for each plume type. Ratios during the oceanic-influenced and jet-like plumes type were significantly greater than ratios during the diffuse-estuarine plume type.

DISCUSSION

Three main findings resulted from this study:

- Primary productivity did not correlate with Chl *a* concentrations most of the time and were best described by differences in plume morphotype.
- Plume morphotypes were important in determining biomass versus productivity relationships; low flow conditions promoted *in situ* productivity while high flow, or 'wash out' conditions promoted highbiomass exported from the Bay.
- N concentration was a poor predictor of N uptake.

Primary productivity did not always correlate well with Chl *a* concentrations, and there was only a weak significant linear relationship for the pooled data (Fig. 2.38; Appendix table A.6). Primary productivity and Chl *a* concentrations were not significantly related during the jet-like plume, were significantly related during the oceanic-influenced plume, and were significantly related (with a weaker R value) for the oceanic-influenced and diffuse-estuarine plume types combined. Nutrient availability was very similar for all three plume types, and PN, PC and Chl *a* concentrations were not different for the jet-like plume type compared to the oceanic-influenced plume type, but the jet-like plume had significantly lower primary productivity rates compared to the oceanic-influenced plume type. The lower rates during the jet-like plume were possibly due to increased mixing below the euphotic zone, creating conditions unsuitable for productivity and instead the biomass observed was transported from the Bay ('wash out'), thus skewing the relationship between primary productivity and Chl *a*.

The differences in solely physical parameters (e.g. wind direction and freshwater flow) among different plume types can have implications on biomass, particulate, and nutrient delivery, as well as primary productivity, and N uptake rates. During jet-like plumes, freshwater flow was as high as 10,000 $m^3\ s^{-1}$ which equates to 0.01 Sv, 1% of the global freshwater flux from rivers. When discharge was this high and winds were predominantly from the north, there was a significant linear relationship between salinity and Chl *a* concentrations (Fig. 2.44), implying Chl *a* from the Bay was exported, or 'washed out', into the adjacent receiving waters. Using a simple flux calculation, a high freshwater flow estimate, and average Chl *a* concenrations during jet-like plumes, biomass from the Bay could exceed 3.5×10^6 g chl d^{-1}. When the plume was diffuse with an estuarine or oceanic influence, there was no correlation between salinity and Chl *a* concentrations (Fig. 2.44) suggesting that 'wash out' from the Bay was not significant during these times and *in situ* processes dominated. However, if Chl *a* was being delivered from the Bay, and the diffuse-estuarine plume type had freshwater flow as low as 300 $m^3\ s^{-1}$, there would only be 9×10^4 g chl d^{-1}, two orders of magnitude lower than the jet-like plume situation. Similarly, since there was no difference in DIN concentrations among plume type, the jet-like plume would provide 2 orders of magnitude more DIN than the diffuse plume, simply due to freshwater flux. However, the oceanic-influenced plume type had almost 3 times more primary productivity on average than the jet-like plume type, and thus the turnover of nutrients would be much greater during the oceanic-influenced plume type. Although a greater flux of DIN is coming from the Bay during the jet-like plume, these nutrients are not being utilized in primary production nearly as much as they are during the oceanic-influenced plume type.

Plume morphotypes were not the only reasons behind the discrepancy between primary productivity rates and Chl *a* concentrations, nor was it the only indicator of 'wash out' from the Bay. Rather, proximity to the source of freshwater flow (i.e. James River) played a large role in skewing relationships. Spatially, the Bay mouth region was expected to be influenced more from nutrient-rich Bay waters due to its proximity to the major tributaries, specifically the James River (Acker et al. 2005), thus leading to higher productivity, however this was not the case. The BM station had greater productivity than the CLT station, but did not have greater productivity compared to the plume stations. Furthermore, freshwater flow at the BM correlated with Chl *a* concentrations, but not particulate matter, inorganic N, N uptake or primary productivity. This is contrary to findings suggesting turbidity and particulate matter can be related to the amount of freshwater flow entering a region as well as the amount of biomass being delivered or produced *in situ* (Berner and Berner 1996; Acker et al. 2005). The implications are that the Chl *a* concentrations were linearly related to high flow but primary productivity was not at the BM station, and the former relationship was a result of Chl *a* 'washed out' from the Bay, and not indicative of higher productivity fueled by nutrients brought in from the estuarine outflow. Furthermore, salinity and Chl *a* were linearly related at the BM station, but salinity was not linearly related with DIN, N uptake, or primary productivity at the BM station. These results were similar to what was observed by Acker et al (2005), however they suggested that the high Chl *a* concentrations were due in part to *in situ* production stimulated by N derived from the Bay proper. Here, I showed that DIN concentrations and N uptake rates were not significantly greater at the BM station compared to the other stations (Figs. 2.25 and

2.44) suggesting that productivity was not differentially stimulated by N from the Bay at the BM station.

The significance of the discrepancy between primary productivity and Chl *a* concentrations, and the potential for 'wash out' of Chl *a*, through the Bay mouth during times of high freshwater flow, and northerly winds, has potential impacts on interpretation of satellite remote sensing of coastal waters. Distinguishing between Chl *a* being produced *in situ* versus that being delivered from an external source, such as the Bay, is crucial for truthing primary productivity algorithms using remotely sensed Chl *a* data in coastal waters. My data suggest that Chl *a* and primary productivity are poorly coupled in estuarine and plume waters during times of high freshwater flow and downwelling-favorable wind conditions. Currently, primary productivity algorithms using remotely sensed Chl *a* in turbid waters in the near-shore Northeastern Atlantic have error estimates between 50 and 100 % (Hoepffner et al. 1999). It has long been known that primary productivity estimates from remotely sensed Chl *a* concentrations have limitations (Behrenfeld and Falkowski 1997). These limitations stem from a lack of knowledge on the physiological state of the algae and their nutrient pre-history, both of which must be understood in order to estimate rates of primary productivity accurately from Chl *a* and both of which are very difficult to examine in the field (Behrenfeld and Falkowski 1997).

N uptake rates were not always a function of N concentration and correlations were sporadic when they did occur with no overlying condition (e.g. plume type, season, or station) dominating the relationships. Early N uptake studies were based on the tenet that N uptake rates were controlled by N availability (kinetics), either in the environment or intracellularly (Goldman and Glibert 1983). However, similar to primary productivity estimates from Chl *a*, kinetic parameters are themselves variable and are a function of phytoplankton physiological status, phytoplankton species, and nutrient pre-history, which again are difficult to ascertain during field sampling (Mulholland and Lomas 2008). Because ambient N concentrations in coastal systems are generally too high, it is often difficult to accurately assess kinetic parameters at lower ranges of nutrient concentrations (Mulholland and Lomas 2008). Furthermore, correlations between *in situ* nutrient concentrations and uptake rates do not signify kinetic relationships. The results presented here suggest some relationship between concentrations of particular N compounds and their uptake, which may signify nutrient preference, and can be indicative of availability.

An important function of N uptake studies however is to understand the relative importance of the various N compounds in fueling primary productivity in the environment. NO_3^-, whether coming from estuarine or oceanic sources, were utilized consistently in the plume region, under varying seasons, station locations, and plume types, while NH_4^+, NO_2^-, urea, and DFAA N had highest uptake rates during the summer and when the plume was diffusive with an estuarine influence. This could suggest that nutrient availability and/or preference during diffusive plumes is dependant upon reduced forms of N, or forms of N that have been biogeochemically altered within the Bay and delivered to the coastal zone. Currently, although agricultural run-off in the forms of NH_4^+ or organic N is the greatest contributor of N to the Bay, the oxidized forms of N are mainly delivered to the Bay. Therefore, for reduced forms of N to have the highest uptake rates in the plume region beyond the Bay, profound N cycling occurred within the Bay (Fig. 1.1) providing altered N forms to the coastal zone for uptake by phytoplankton.

Rate measurements for N uptake are few and data collection in this area has been sporadic and temporally and spatially limited. N uptake rates reported here were consistent with those observed in other coastal systems (Mulholland and Lomas 2008) but are only the second set of uptake rates reported for the Chesapeake Bay plume (Glibert et al. 1991; Glibert and Garside 1992). Glibert et al. (1991) reported that between 60 and 80 % of the total N taken up in the Chesapeake Bay plume region was in the form of urea. During this study, between 9 and 90% of the total N taken up was in the form of NH_4^+, for all seasons, with percentages highest in the spring, even though total N uptake rates were greatest overall in the summer. Differences in N uptake rates between this study and the 1985 – 1986 study may simply reflect interannual variability, the timing of seasonal transitions from year to year (e.g., spring freshet), or changes in nutrient availability and N processing. Despite similar annual average flows during 2005, 2006, and 2007, timing of flow within those years varied substantially. Past research within the Bay proper and in other estuarine systems suggested that the timing of rainfall events during an overall low discharge period is important because it can control the amount of nutrients available for primary productivity and also the delivery of nutrients to the coastal zone (Fisher et al. 1988; Malone et al. 1988; Fisher et al. 1992). Therefore, the timing of rainfall events in the upper Bay, will determine the biogeochemical impact, in terms of the net N flux, of the plume on the coastal ocean. Coastal eutrophication and N loading in the United States has increased approximately six-fold since the 1960's (Howarth et al. 2002; Howarth 2004) and so differences between this study and the one performed in the 1980's may also be due to accelerated anthropogenic forcing and changes in the timing of the spring blooms.

C productivity and N uptake are highly variable, both temporally and spatially in the region of the Chesapeake Bay outflow plume and seasonal variability may be less important than freshwater discharge (which affects flow through the Bay mouth) and oceanographic conditions (e.g., upwelling or downwelling-favorable winds) at the time of the discharge, thus affecting plume morphotype. We found that the predominant wind direction, which influences local upwelling and downwelling conditions, is extremely important in determining the extent of the plume's intrusion into coastal waters. Seemingly, when the plume is a jet, as it is during downwelling-favorable conditions, its influence is restricted to a narrow coastal area where material is processed and likely consumed, and primary productivity does not correlate with biomass, suggesting that the biomass present during a jet-like plume is 'wash out' from the Bay. Productivity is not stimulated during this time. In contrast, when the plume is diffusive, e.g., during upwelling favorable conditions, or has an oceanic influence, the effect of the plume on the coastal ocean is stronger in the sense that N uptake rates were greater, and primary productivity correlated with nutrient availability, and this may have more profound impacts on ecosystem productivity. Superimpose on this the predominant flow patterns and we see that high flow during the summer, when there is higher likelihood of upwelling favorable conditions, can have an enormous impact on the coastal ocean, particularly during high discharge events. It has been shown that up to half of the annual N load can be delivered to a coastal system (specifically Pamlico Sound, south of the Chesapeake Bay mouth) during large stochastic events such as hurricanes (Paerl et al.

2001). Future climate change scenarios suggest that low frequency, high intensity events may become the norm. If this indeed is the case, the timing of these events and the period in between these events, with respect to the dominant wind direction and consequent wind-induced upwelling or downwelling, will play a crucial role in determining the impact of estuarine plumes on the coastal ocean.

This data provides current estimates of natural processes and suggests substantial variability in productivity and N dynamics in an estuarine plume. While high-intensity and long-term data is needed to truly understand processes and controls of primary productivity in highly variable coastal regions influenced by estuarine plumes, these snapshots provide important insights regarding the dominant physical and biogeochemical forcing behind productivity. In addition, primary productivity was not simply related to Chl *a* concentrations, and understanding plume morphotype is crucial to determining productivity relative to Chl biomass. Further, N uptake was not always related to nutrient concentration in the environment, suggesting nutrient preferences were significant.

CHAPTER III

NITROGEN AND CARBON PRODUCTIVITY IN THE MID-ATLANTIC BIGHT: TEMPORAL AND REGIONAL COMPARISONS

INTRODUCTION

While the global coastal ocean (< 200 m) represents less than 10% of the world's ocean, these highly productive regions are thought to account for more than 21% of total oceanic productivity (Gattuso et al. 1998; Jahnke 2007). Primary production in most coastal and shelf systems is thought to be limited by nitrogen (N) (Dugdale and Goering 1967; Ryther and Dunstan 1971), however these areas are impacted by adjacent landmasses and receive anthropogenic N inputs that can potentially alleviate this limitation. Consequently, in addition to upwelled N from oceanic waters, productivity in these areas is often controlled by "new" N inputs (sensu Eppley and Peterson 1979) from terrestrial sources such as rivers and groundwater discharge, and from atmospheric deposition. It has been determined that denitrification in freshwater, terrestrial, and estuarine sediments removes a substantial (between 80 and 90%) amount of reactive N before entering the coastal zone (Fennel et al. 2006; Galloway et al. 2008) and that another 15% is denitrified in continental shelf sediments (Galloway et al. 2008). Due to such high denitrification rates, and the loss of N to the sediments, it would appear that riverine and terrestrial run-off may not deliver N necessary to fuel primary productivity in the coastal zone (Seitzinger et al. 2006). Alternatively, riverine N loading to the coastal U.S. has almost doubled over the past forty years and it is projected that these inputs will increase by another 30 % over the next 30 years (Howarth et al. 1996;

Howarth et al. 2002), thus there is the possibility that the normally denitrifying sediments could become saturated with reactive N. If the sediments become saturated with N, they could become a source of N to an N-limited system (Galloway et al. 2008).

The N budget in the MAB is an important driver of primary production in this N-limited area, and therefore is tightly tied to the carbon (C) budget (Howarth 2004; Gruber and Galloway 2008). Increases in primary productivity have been related to increases in anthropogenic N inputs into the coastal zone (Howarth et al. 2002, Paerl and Piehler in press, Seitzinger and Harrison in press) and the Redfield ratio is often used to estimate primary productivity from N uptake and vice versa. However, this estimate may not be useful in an increasingly eutrophic environment, specifically due to the shifts in the absolute amount and dominant source or form of N delivered to the coastal ocean that can have major impacts on primary productivity and the dominant primary producers (Gruber and Galloway 2008). How N availability will affect the ocean's ability to continue to take up C is centered on understanding 'nitrogen-carbon-climate interactions' (Gruber and Galloway 2008). Quantifying current regional N dynamics will not only help resolve N budgets and primary productivity in coastal regions, but will allow us to begin to project what the future might hold under evolving climate change scenarios (Howarth 2004).

Large-scale shifts in the physical environment and nutrient delivery to coastal regions can have great consequences for coastal productivity. Physical processes within the coastal zone regulating temperature and stratification are important controls on N availability and primary productivity, and those water movements dominate the annual cycle of productivity in the MAB (Flagg et al. 2002; Lentz 2003; Rasmussen et al. 2005).

Specifically, the flow of the cold Labrador current from the north interacts with the warm oligotrophic Gulf Stream current from the south creating a complicated pattern of seasonal stratification and destratification that is highly dependent on wind speed, direction, duration, and eddy development (Flagg et al. 2002). In the summer months, along the North American Mid-Atlantic coast, stratification occurs, thus limiting vertical transport of nutrients, and primary productivity within the water column (Flagg et al. 2002). Salty intrusions of slope water increase during the summer in the along-shelf direction (from north to south), thus leading to higher salinity waters on the shelf in the summer (Flagg et al. 2002; Lentz 2003). This is followed by an overturning of waters and higher productivity in the fall due to wind-driven mixing and cooling, leading to well-mixed conditions in the winter (Wright and Parker 1976; Rasmussen et al. 2005). Increased light and nutrient availability leads to high productivity in the spring.

In addition to anthropogenic N inputs and physical forcing, primary productivity in the MAB and other coastal areas may be affected by increasing atmospheric carbon dioxide (CO_2) concentrations and/or projected temperature rises in the future, as has been observed in the oligotrophic North Atlantic and in mesocosm experiments (Hein and Sand-Jensen 1997; Riebesell et al. 2007). The sensitivity of coastal regions to increasing CO_2 and water temperature are largely unknown and so the future of these systems as sources or sinks of atmospheric CO_2 is in question (Riebesell et al. 2007). While ocean margins, including the MAB, are thought to be sinks for atmospheric CO_2, there is no current consensus regarding the MAB as a net source or sink of atmospheric CO_2 (Chavez et al. 2007).

The MAB has a complicated physical regime and receives N from a variety of sources; as a result, there are contrasting views of the N budget for this region. Past experimental results and recent modeled biogeochemical results for the pelagic MAB suggested that denitrification in the sediments removed 90% of all DIN and PON entering the region from the north and from riverine sources (Seitzinger and Giblin 1996; Fennel et al. 2006). However, the modeled inputs for N uptake utilized half-saturation constants for NO_3^- and NH_4^+ uptake only (Fennel et al. 2006) when N uptake is not based solely on nutrient concentration. There can also be significant uptake of N sources not normally measured, such as NO_2^-, urea, and DFAA N particularly in coastal regions where recycled nutrients can dominate (Lipschultz 2008) (see Ch. 2). Other imbalances in the N budget stem from undersampling of N_2 fixation. Estimates of denitrification for the MAB (2.3×10^{12} mol N y^{-1}) are an order of magnitude greater than N_2 fixation estimates for the region, suggesting either underestimates of N_2 fixation or overestimates of denitrification (Fennel et al. 2006). Research in the Naragansett Bay and surrounding coastal areas suggest that sedimentary N losses due to denitrification may be balanced or even exceeded by sedimentary N_2 fixation, thus creating a source of N to the coastal ocean (Fulweiler et al. 2007). Further, climate change, superimposed on eutrophication, may alter the balance between N retention and losses due to changes in primary production and the amount of organic material available for dentrification in the sediments (Fulweiler et al. 2007).

Uncertainties regarding a balanced N budget in the MAB stem from a lack of knowledge of current N requirements for primary production during times when N is increasing in an N-limited coastal system. Multiple N forms are available for uptake at any given time, and importance needs to be placed on understanding differences between inorganic N uptake versus organic N uptake, as phytoplankton may be competing with bacteria in taking up organic N (Mulholland and Lomas 2008). Furthermore, knowing how much and what forms of N are taken up in different hydrographic regimes and on a seasonal scale will further broaden our view of the region as a net source or sink of atmospheric CO_2. It is the intent of this research to quantify N uptake rates for inorganic and organic compounds as well as primary productivity estimates over 4 seasons in the coastal zone of the MAB between Delaware and Virginia. From these measurements, a comparison of primary productivity and N utilization can be made across regions and over an annual timescale and will be useful in assessing the region's ability to take up C and N over time by comparing to literature values. This analysis will provide essential and current information useful for modeling, algorithm development, and assessment of the region in regards to its ability to take up atmospheric CO_2.

METHODS

Five cruises were undertaken over two years during late winter/early spring, spring, summer, and fall (30 March – 2 April 2005; 26 – 30 July 2005; 9 - 12 May 2006; 2 – 5 July 2006; 30 October – 2 November 2006). Primary productivity rates, N uptake rates, and nutrient concentrations were measured during 3-5 day sampling excursions. Stations included locations in the Chesapeake Bay mouth and its outflow plume, the Delaware Bay outflow plume, waters influenced by the Gulf Stream, and the non-estuarine influenced continental shelf between the Delaware Bay and Chesapeake Bay (Fig. 3.1). Cruises were aboard the *R/V Cape Henlopen* or *R/V Hugh R. Sharp* and were generally comprised of on-shore to off-shore or off-shore to on-shore sampling transects each day.

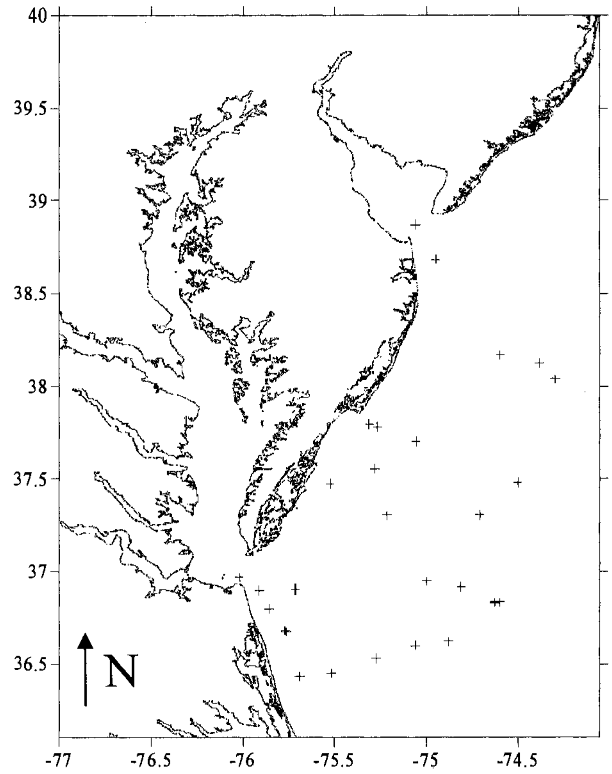

Fig. 3.1. Station map for all MAB cruises.

Measurements were made at each station using a rosette-mounted CTD (SeaBird electronics) similar to what was described in Chapter 2. Water samples were collected using rosette-mounted Niskin bottles at both the surface (D1: 0 - 2 m) and fluorescence maximum (D2: 4.5 – 18 m in the plume region; 10 – 50 m in the southern shelf; 5 – 53 m in the mid-shelf). When the water column was well-mixed or shallow, samples were collected from the upper 2 m and 1 m above the bottom to facilitate calculation of depth integrated areal productivity. Water collection and analyses for nutrients and particulates were described in detail in Chapter 2 and protocols and methods were adhered to during these cruises. Nutrients (NO_2^-, NO_3^-, urea, PO_4^{3-}, and SiO_4^{4-}) were analyzed on an Astoria Pacific nutrient auto-analyzer according to manufacturer specifications using standard colorimetric methods (Parsons et al. 1984; Price and Harrison 1987). The manual phenol-hypochlorite method was used for NH_4^+ analyses (Solorzano 1969). Total dissolved nitrogen (TDN) was analyzed as NO_3^- after persulfate oxidation (Valderrama 1981). DON was calculated as the difference between TDN and dissolved inorganic N (DIN). DFAA N was analyzed via high performance liquid chromatography (HPLC) (modified from Cowie and Hedges 1992). Chl *a* samples were analyzed fluorometrically within 5 days of collection (Welschmeyer 1994). Calculations, detection limits, accuracy, and precision were the same as described in the methods for Chapter 2.

Water samples were fixed with mercuric chloride and sealed in gas tight glass vials for dissolved inorganic carbon (DIC) analysis using an UIC Inc. CO_2 coulometer (Johnson et al. 1985). Alkalinity was measured on the same samples using a Brinkman Titrino titrator (Dickson 1981). Surface water CO_2 concentrations (pCO_2) were calculated based on alkalinity, DIC concentrations, temperature, and salinity based on calculations in Sarmiento and Gruber (2006) (Eq. 3.1).

$$pCO_2 = \frac{K_2}{K_0 * K_1} * \frac{(2 * DIC - Alk)^2}{Alk - DIC} \qquad \text{Eq. 3.1}$$

The equilibrium constants are calculated in Eq.3.2 (Weiss 1974), and in Eqs. 3.3 and 3.4 (Mehrbach et al. 1973; Dickson and Millero 1987).

$$\ln K_0 = -60.2409 + 93.4517 \times (100/T) + 23.3585 \times \ln(T/100) + S \times (0.023517 - 0.023656 \times (T/100) + 0.0047036 \times (T/100)^2) \quad \text{Eq. 3.2}$$

$$-\log K_1 = -62.008 + 3670.7/T + 9.7944 \times \ln(T) - 0.0118 \times S + 0.000116 \times S^2 \quad \text{Eq. 3.3}$$

$$-\log K_2 = 4.777 + 1394.7/T - 0.0184 \times S + 0.000118 \times S^2 \quad \text{Eq. 3.4}$$

N and C uptake and primary productivity experiments were conducted aboard the ship in either 250 mL or 500 mL acid-washed incubation bottles (PETG), similar to what was described in Chapter 2. For bicarbonate uptake, four or 24-hour incubations were done to measure integrated daily net bicarbonate uptake. Reported rates of daily photosynthesis were calculated by multiplying by 12 hours for the 4-hour incubations, and 24 hours for the 24-hour incubations.

Areal rate calculations were conducted by converting daily rates of either total N uptake rates or primary productivity rates, made over four seasons and two years, to annual areal rate estimates for each region. First, primary productivity and N uptake rates were averaged over the two sampling depths, justified by the fact that rates at both depths in each region were not significantly different, and this is discussed further in the Results section. These averaged rates were then multiplied by the euphotic depth. The euphotic depth, typically defined as 1% of photosynthetic active radiation (PAR), was determined based on several different measurements, as PAR sensor data were not reliable for all cruises. In some cases, *in situ* radiometry measurements of the water leaving irradiance at 490 and 555 nm (nLw490/nLw555) were provided by scientists from NASA (Stan Hooker, unpublished data). The euphotic depth was also obtained from the diffuse attenuation coefficient at 490 nm (K490) from either SeaWifs or MODIS and converting it to the euphotic depth using NASA's algorithm (Eq. 3.5) where ln(surface light – ln(light at compensation depth) is equal to ln(100):

$$\text{Euphotic depth} = \frac{\ln(\text{surface light}) - \ln(\text{light at compensation depth})}{\text{K490}} \qquad \text{Eq.3.5}$$

Since the euphotic depth was determined by different means depending on the cruise, decision criteria were developed to be able to choose the appropriate depth for the extent of the euphotic zone. First, if the measured or modeled (i.e. 1% PAR, radiometry, or K490) depths were greater than the actual depth of the water column, the depth of the water column was used as the euphotic depth. If no measured or modeled parameters were available, and the fluorescence maximum was equal to the depth of the water column, the depth of the water column was used as the euphotic depth. If only 1% PAR measurements were available, then the depth of 1% PAR was used as the euphotic depth. Finally, if no modeled or measured data was available, and the fluorescence maximum was less than the depth of the water column, the fluorescence maximum depth was used as the euphotic depth and this assumption was only made at 8 of 61 total stations for all five cruises. The variability between the fluorescence maximum being equal to the euphotic depth and the 1% PAR measurement when available ranged from 2 m to 10 m. Results of the euphotic depths used for these calculations and the method used to determine the euphotic depth at each station are depicted in Appendix Table B.6. Once the averaged rates were multiplied by the euphotic depth (units: mol C (N) m^{-2} d^{-1}) annual averages were calculated by integrating these values across seasons: Winter (March

2005), Spring (May 2006), Summer (averaged July 2005 and 2006), and Fall (Oct/Nov. 2006). Once daily rates were calculated for each season they were each multiplied by 91.25 d (365 days divided by 4) and then added together to get a seasonally integrated annual rate for each region. Finally, annual rates were calculated for each region by multiplying of the surface area of the PL, MS, and SS regions. These surface areas were obtained from the sampling boundaries put forth by each cruise: PL: 37 – 36.4N; 76 – coastal land boundary along the eastern border; SS: 36.4 – 37N; 75.5 – 74. 4W; MS: 37 – 38.5N; coastal land boundary along eastern border – 74W.

All surface maps were constructed using Golden Software Surfer 8 using data from NOAA's coastline extractor. Statistical analyses, such as one-way ANOVA's and correlations, were performed using SigmaStat and are similar to those reported in Chapter 2.

RESULTS

HYDROGRAPHIC REGIME

The hydrographic regime of the sampling region varied greatly between cruises (Fig. 3.2). Based on temperature and salinity, the study region was separated into three major hydrographic regions: 1) plume regions (PL), where biological processes were largely influenced by terrestrial inputs from the Chesapeake Bay and Delaware Bay; 2) the mid-shelf region (MS) north of the Chesapeake Bay mouth, where oceanic and coastal process converged; and 3) the southern shelf region (SS) where the Gulf Stream influence often intruded with warm, salty water and oceanic processes such as advection influenced the biological framework. Temperature-salinity diagrams show that the range in surface salinity was the greatest (between 22 and 31) for the PL region, as might be expected due to the influence of freshwater and tidal fluctuations (Fig. 3.2; see Ch. 2). It was difficult to differentiate the MS and the SS regions in the temperature-salinity diagrams; however the density anomalies for the SS were primarily between 22 and 28 kg m^{-3} and for the MS they were between 20 and 28 kg m^{-3} (Fig. 3.2). Surface salinity in the SS and MS did not vary greatly, with the SS always between 32 and 36 and the MS between 33 and 36. A wide range of temperatures were observed in the region, with lowest temperatures (6 °C) observed during spring 2005 and highest temperatures (27 °C) observed during summer 2005 in all three regions.

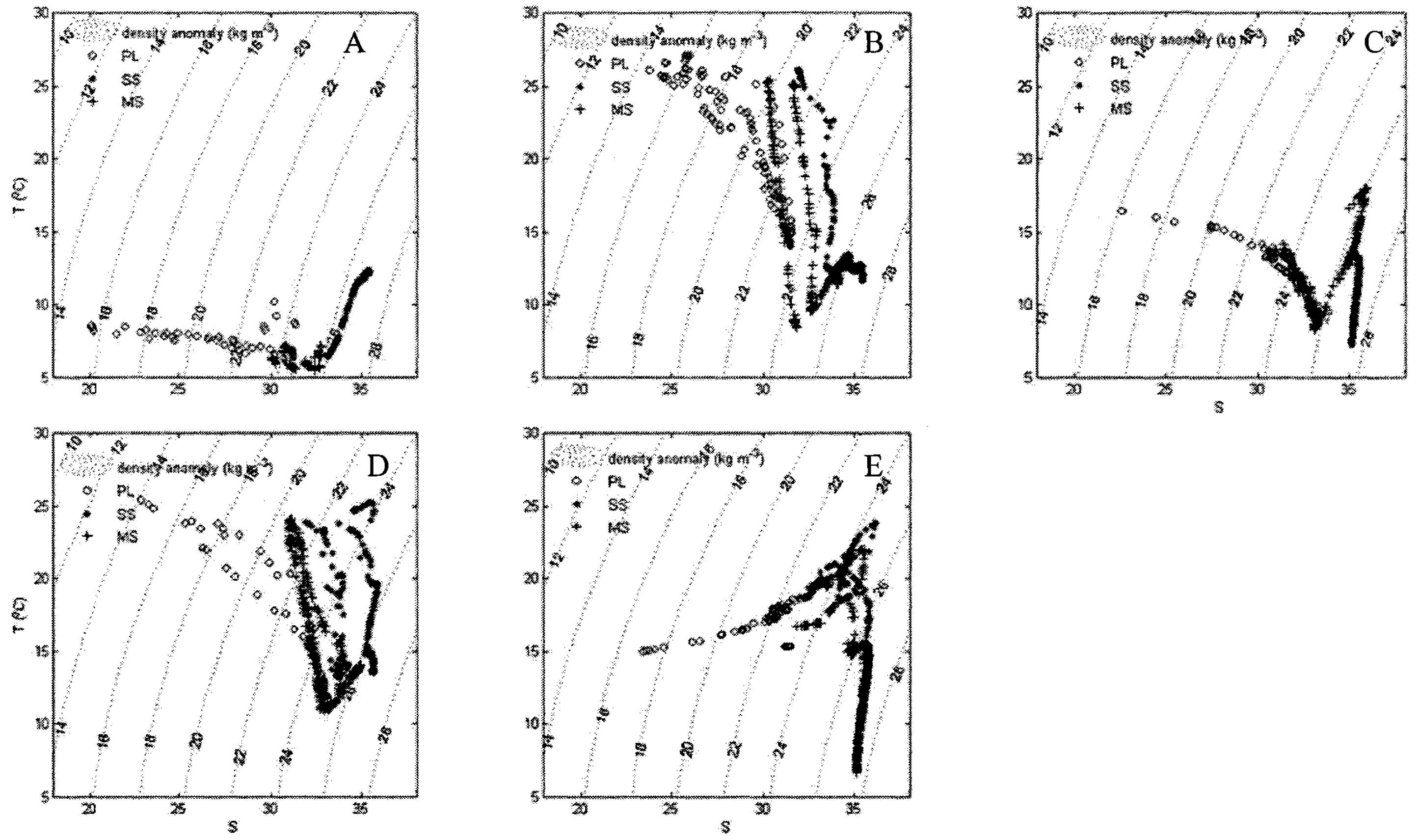

Fig. 3.2. Temperature- Salinity diagrams for each cruise: 3/05 (A), 7/05 (B), 5/06 (C), 7/06 (D), 11/06 (E). Dashed lines are density anomaly contours.

During late winter (March 2005), surface salinity in the plume ranged between 22 and 33, and the water column was stratified primarily due to salinity differences between surface and deeper waters while the water column at SS and MS stations was well-mixed (Fig. 3.2A). At this time downwelling-favorable winds from the north created a strong estuarine outflow plume exiting the Chesapeake Bay, and low salinity waters hugged the coast to the south of the Bay mouth (see Ch.2 Table 2.2). Surface temperatures ranged between 6 and 10 °C throughout the study region and there was no apparent influence of warmer Gulf Stream water (Fig. 3.2A).

Surface salinity in summer (July 2005) was similar to surface salinity in March 2005 throughout the study area, ranging between 24 and 32. The water column was stratified in plume influenced areas as well as outside of the plume influenced areas (Fig. 3.2B), but due to upwelling-favorable winds, the plume was diffuse (see Ch. 2 Table 2.2). Surface water temperature throughout the region ranged from 25 to 27 °C (Fig. 3.2B).

In spring (May 2006), a period of strong and sustained winds from the north preceded the field campaign causing off-shore transport of surface water and a large salinity range in the surface waters throughout the study area (24 – 36). A jet-like outflow plume was observed exiting the Chesapeake Bay, and there was a low salinity patch surrounding the mouth of the Chesapeake Bay (see Ch.2 Table 2.2). Surface water temperatures in the SS and MS regions ranged between 10 and 16 °C. Similar to the previous spring cruise, the PL stations were stratified and the SS and MS stations were well-mixed (Fig. 3.2C). Satellite imagery of sea surface temperature, obtained from Rutgers University Coastal Ocean Observation Lab, suggests there was no Gulf Stream influence along the SS (Fig. 3.3), however warm water (>16 °C) was observed along the 600 ft isobath.

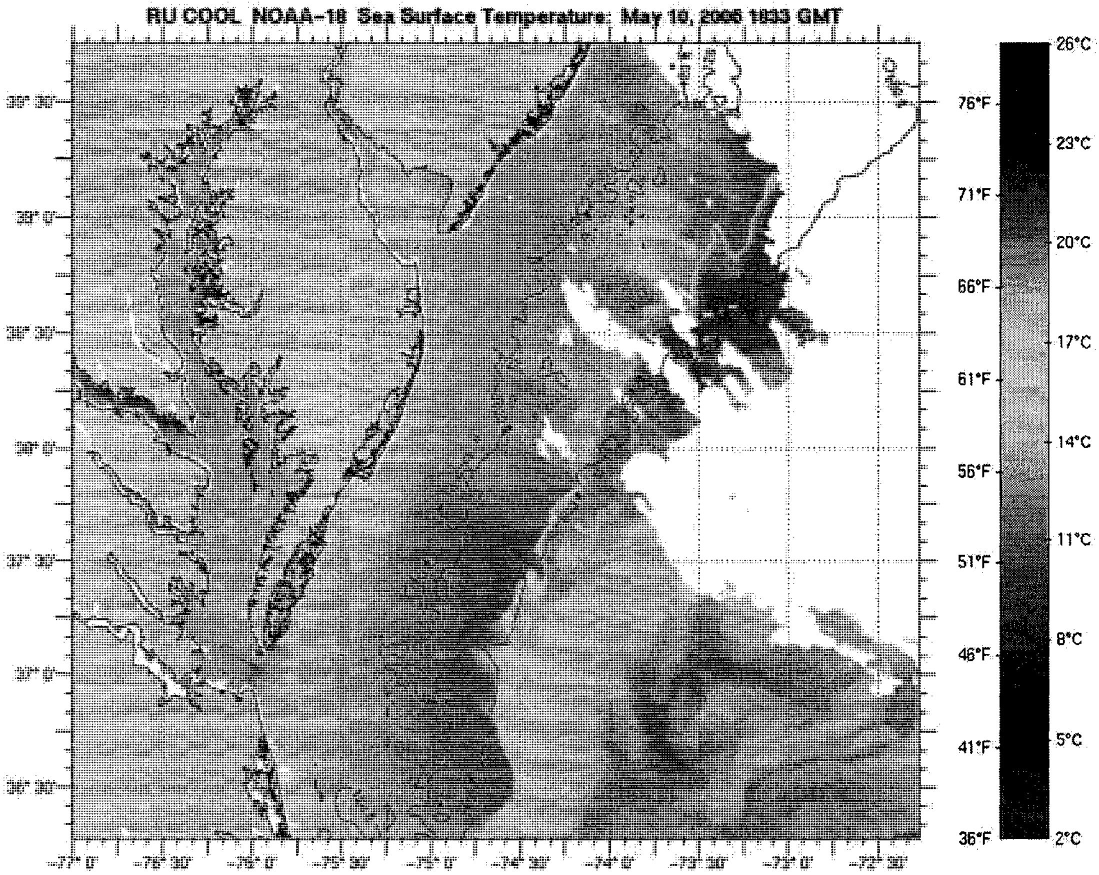

Fig. 3.3. Satellite imagery map of MAB sea surface temperature for 10 May 2006. Warm surface waters (> 16 °C) are depicted along the 600 ft isobath. Satellite imagery was downloaded from Rutgers University, RUCOOL website (http://marine.rutgers.edu/cool/sat_data/?nothumbs=0).

Just before the July 2006 cruise, there was a large and protracted rainfall event and associated high winds from the south along the east coast of the U.S. (see Fig. 2.2). The freshwater input resulted in a highly stratified water column in the plume (Fig. 3.2D) and a slightly larger range in surface salinities (23 - 35) in the plume relative to those observed during the summer 2005 (24 - 32). The outflow plume from the Chesapeake Bay was diffusive, as low salinity waters were observed east of the Bay mouth and winds were from the south (see Ch.2 Table 2.2). Temperatures were slightly lower in July 2006 relative to July 2005, ranging between 21 and 25 °C. However, higher temperature and salinity at offshore stations suggest more Gulf Stream influence at the offshore stations during 2006 (Fig. 3.2D). Relative to 2005, water temperatures were lower and salinity was high in the MS region along the eastern shore of Virginia (north of the Chesapeake Bay mouth) suggesting upwelling of nutrient-rich waters. Upwelling-favorable winds coming out of the south were observed prior to the cruise supporting this idea.

During Oct/Nov 2006, surface water salinity ranged between 24 and 35 and surface water temperatures ranged between 15 and 22 °C during the cruise (Fig. 3.2E). Lower salinity water was observed along the coast to the south of and near the Bay mouth, however southeasterly winds preceded the sampling event and colder water was observed along the coastline, both indicative of upwelling-favorable conditions. Sea surface temperature satellite imagery, obtained from Rutgers University Coastal Ocean Observation Lab showed cold waters surrounding the Bay mouth and then interacting with meanders of warm water, likely from the Gulf Stream, at the offshore stations coming from the south (Fig. 3.4). Stations in the plume were stratified and MS and SS were weakly mixed with warm low salinity water at the surface and cool salty water at depth (Fig. 3.2E).

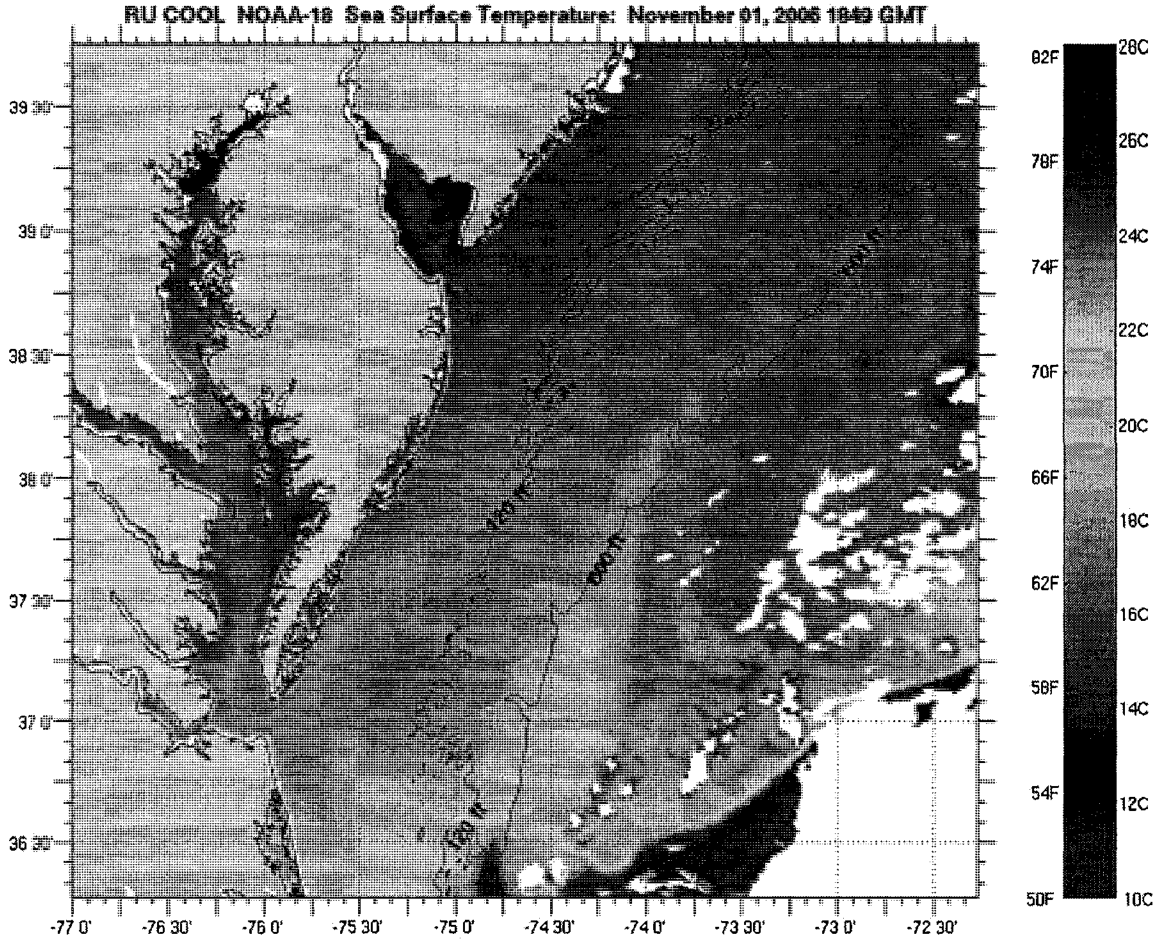

Fig. 3.4. Satellite imagery map of MAB sea surface temperature for 01 November 2006. Cold surface waters are depicted exiting the Bay and interacting with warm Gulf Stream meanders. Satellite imagery was downloaded from Rutgers University, RUCOOL website (http://marine.rutgers.edu/cool/sat_data/?nothumbs=0).

NUTRIENT REGIME

The range of DIN (DIN = NH_4^+ + NO_3^- + NO_2^-) concentrations, for every cruise and at every station, was not significantly different between surface waters (0.1 – 4.3 μmol L^{-1}; mean = 1.0 ± 0.9 μmol L^{-1}) and at depth (0.2 – 4.2 μmol L^{-1}; mean = 1.2 ± 0.9 μmol L^{-1}) (Appendix Tables A.1 and B.1). DIN concentrations at the PL stations were not significantly different between depths (D1: 0.5 – 1.5 μmol L^{-1}; D2: 0.5 – 1.3 μmol L^{-1}; Appendix Table A.1) even though the water column was mostly stratified. At the SS stations, DIN concentrations were not significantly different between depths (D1: 0.3 – 1.2 μmol L^{-1}; D2: 0.3 – 2.4 μmol L^{-1}; Appendix Table B.1) except for at the offshore stations, where surface DIN concentrations during summer and fall 2006 ranged from 0.4 to 0.6 μmol L^{-1} and at depth they ranged from 2.4 to 3.9 μmol L^{-1} (Appendix table B.1). Similar results were found at the MS stations, where DIN concentrations were not significantly different among depths (D1: 0.1 – 2.6 μmol L^{-1}; D2: 0.2 – 3.9 μmol L^{-1}; Appendix Table B.1). Average DIN concentrations were not significantly different among regions (Fig. 3.5). However, NO_3^- concentrations were significantly greater in the SS region compared to the PL region (Fig. 3.5).

Seasonally, the greatest DIN concentrations were observed during March 2005 at the deepest offshore stations in the SS region (4.2 μmol L^{-1} at both depths) primarily due to high concentrations of NO_3^- and likely a result of upwelling at the slope/shelf interface as that region was well-mixed at the time (Fig. 3.2A). Also, high DIN concentrations were observed in the Bay mouth during Oct. 2006 (4.8 μmol L^{-1}) (Appendix Table B.1). When samples were averaged for each season, DIN concentrations (specifically NO_3^-) were greater in the fall and winter compared to the spring and summer (ANOVA; Tukey test; $p < 0.05$; Fig. 3.6). NH_4^+ concentrations were significantly greater in the winter compared to the spring, summer, and fall, and the fall and summer concentrations were greater than the spring concentrations (ANOVA; Tukey test; $p < 0.05$; Fig. 3.6). NO_2^- concentrations in the fall were significantly greater than in the winter, spring, and summer (ANOVA; Tukey test; $p < 0.05$; Fig. 3.6).

There were no significant relationships between DIN concentrations and physical parameters among regions, except for in the SS region, where there were significant negative linear relationships between temperature and NH_4^+ concentrations ($R = -0.788$; $p < 0.05$), and salinity and NH_4^+ concentrations ($R = 0.564$; $p < 0.05$). Furthermore, in the fall, there were significant negative linear relationships between NH_4^+ concentrations and temperature ($R = -0.608$; $p < 0.05$) and salinity ($R = -0.601$; $p < 0.05$). During the fall, cool waters were exiting the mouth of the Chesapeake Bay (Fig. 3.4), and therefore inferring from the negative linear relationship with temperature and salinity, bringing nutrients, specifically NH_4^+, into the coastal zone.

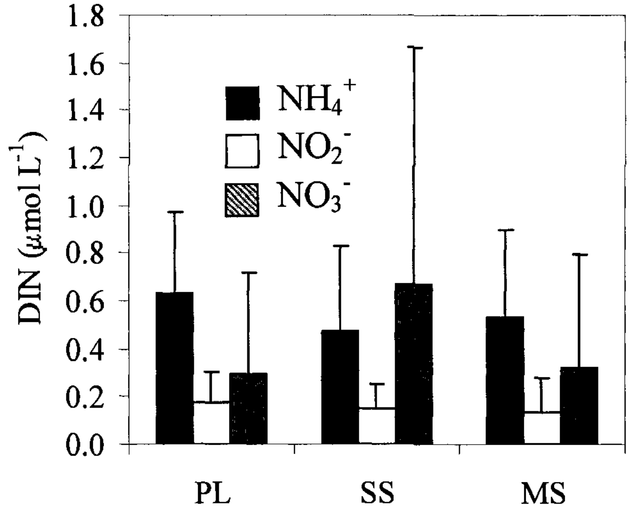

Fig. 3.5. NH_4^+, NO_2^-, NO_3^- concentrations averaged for each region. There were no significant differences among regions for NH_4^+ or NO_2^- concentrations but NO_3^- concentrations were significantly greater at the SS stations compared to the PL stations.

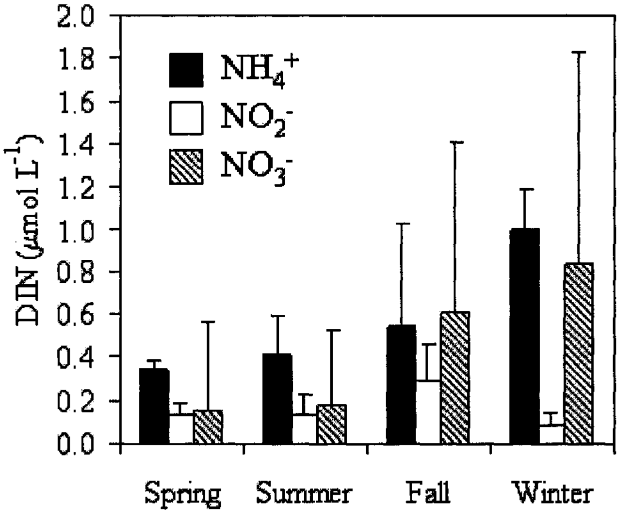

Fig. 3.6. NH_4^+, NO_2^-, NO_3^- concentrations averaged for each season. NH_4^+ concentrations were significantly greater in the winter compared to the spring, summer, and fall. NO_2^- concentrations were greater in the fall compared to the spring, summer, and winter. NO_3^- concentrations were greater in the winter and fall compared to the spring and summer.

The largest proportion of total measured dissolved N (NH_4^+, NO_2^-, NO_3^-, urea, and DFAA) at PL and MS stations was generally NH_4^+ (39% and 34% of measured dissolved N, at surface and at depth, respectively). However, NO_3^- was often the dominant N form at the SS stations at depth (as high as 80% of measured dissolved N) particularly at the offshore stations, suggesting possible upwelling of NO_3^- at the shelf/slope interface (Appendix Table B.1).

Urea N concentrations averaged 0.2 ± 0.2 μmol N L^{-1} at both sampling depths and therefore there was no significant difference in urea concentrations between depths. Urea concentrations ranged from below the limit of detection to 1.2 μmol N L^{-1} for all regions (Appendix Table B.1). For DFAA N, there were no significant differences between depths for all regions combined (D1: 0.27 ± 0.24 μmol N L^{-1}; D2: 0.39 ± 0.39 μmol N L^{-}1). Serine, alanine and glycine were the most abundant amino acids quantified (11 - 18%, 6 – 8%, and 12 – 18% of the total measured DFAA N pool, respectively; data not shown). DON concentrations were not significantly different between surface waters (D1: 12.1 ± 6.3 μmol N L^{-}1) and at depth (D2: 11.7 ± 6.6 μmol N L^{-1}). The lowest concentrations of DON for the whole study area were observed in July 2006 (D1: 2.2 – 10 μmol N L^{-1}; D2: 3.3 – 8.3 μmol N L^{-1}), excluding one outlier at the Bay mouth (Appendix table B.1). There were no significant differences among regions for averaged urea and DFAA N concentrations, but DON concentrations were significantly greater at the PL and MS regions compared to the SS region (ANOVA; Tukey test; $p < 0.05$; Fig. 3.7).

Seasonally, when urea concentrations were averaged, concentrations in the winter were significantly greater than in the spring and summer, and concentrations in the fall were significantly greater in the summer (ANOVA; Tukey test; $p < 0.05$; Fig. 3.8). DFAA N concentrations were significantly greater in the winter compared to the spring, summer, and fall (ANOVA; Tukey test; $p < 0.05$; Fig. 3.8). DON concentrations were significantly greater in the winter and spring compared to the summer and fall, and greater in the fall compared to the summer (ANOVA; Tukey test; $p < 0.05$; Fig. 3.8).

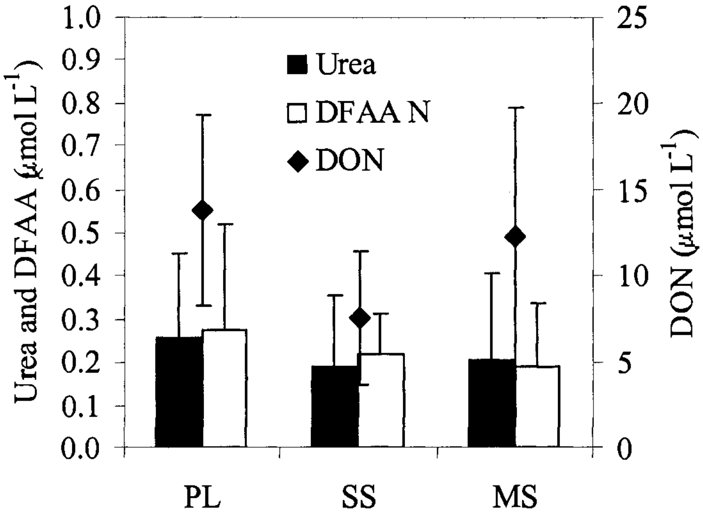

Fig. 3.7. Urea, DFAA N, and DON concentrations averaged for each region. There were no significant differences a regions for urea and DFAA N, but DON concentrations were significantly greater in the PL and MS regions compared to the SS region.

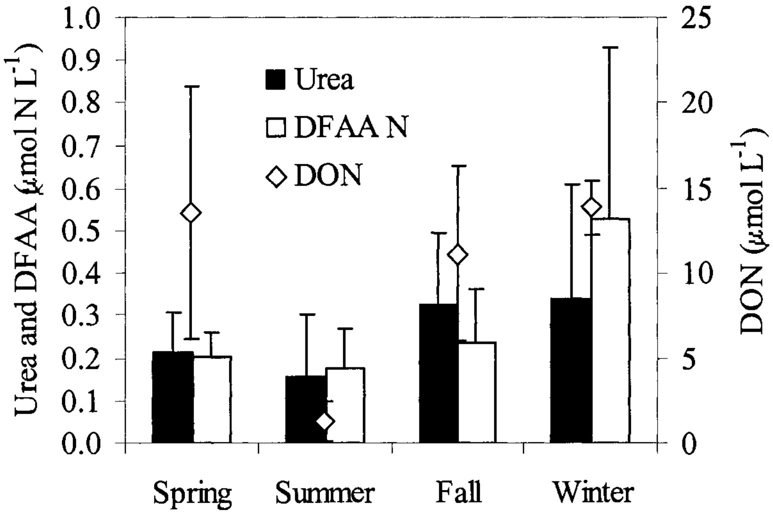

Fig. 3.8. Urea, DFAA N, and DON concentrations averaged for each season. Urea was significantly greater in the winter compared to the spring and summer, and greater in the fall compared to the summer. DFAA N concentrations were greater in the winter compared to the spring, summer, and fall. DON concentrations were significantly greater in winter and spring compared to the summer and fall, and significantly greater in the fall compared to the summer.

Concentrations of PO_4^{3-} ranged from below the limit of detection (0.02 μmol L^{-1}) to 0.5 μmol L^{-1} for all pooled data (Appendix Table B.2). Concentrations of SiO_4^{4-} ranged from 0.06 to 15 μmol L^{-1} for all pooled data (Appendix Table B.2). There was no significant difference between regions for averaged PO_4^{3-} concentrations ($p > 0.05$; Fig. 3.9) but SiO_4^{4-} concentrations were greatest in the PL region compared to the SS and MS regions (ANOVA; Tukey test; $p < 0.05$; Fig. 3.9). When concentrations were averaged for each season, PO_4^{3-} concentrations were significantly greater in the winter compared to the spring, summer, and fall (ANOVA; Tukey test; $p < 0.05$; Fig. 3.10). SiO_4^{4-} concentrations were significantly greater in the fall compared to the spring, summer, and winter (ANOVA; Tukey test; $p < 0.05$; Fig. 3.10). DIN:DIP ratios were most often less than 16, suggesting greater PO_4^{3-} concentraions than DIN in regards to the Redfield ratio, therefore suggestion N limitation. Some exceptions were the SS and PL stations during the summer cruises when ratios were greater than 16 (Fig. 3.11). SiO_4^{4-} did not appear to be limiting to diatom growth (DIN:SiO_4^{4-} <1), and again N limitation, based on Redfield standards were observed, except in March 2005 (Fig. 3.12).

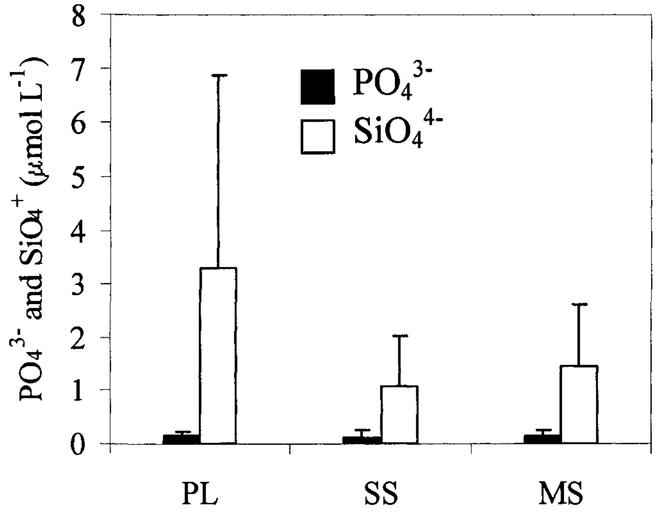

Fig. 3.9. PO_4^{3-} and SiO_4^{4-} concentrations averaged for each region. There were no significant differences among regions for PO_4^{3-}, but SiO_4^{4-} concentrations were significantly greater in the PL region compared to the SS and MS regions.

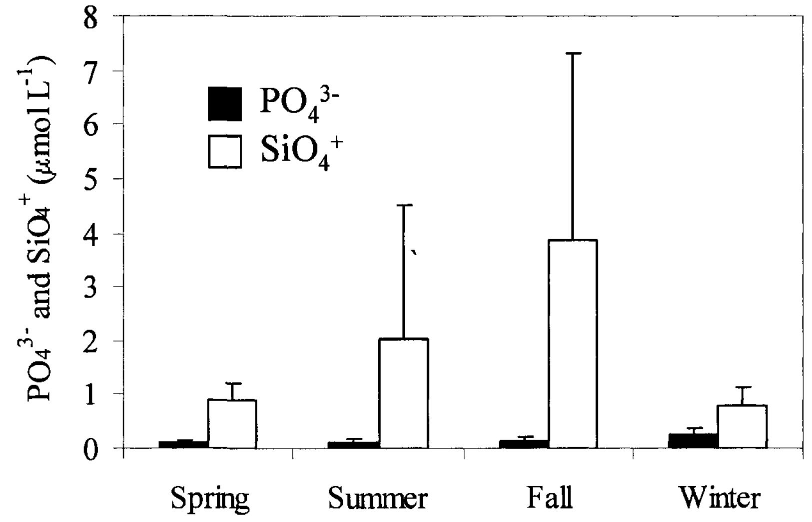

Fig. 3.10. PO_4^{3-} and SiO_4^{4-} concentrations averaged for each season. PO_4^{3-} concentrations were significantly greater in the winter compared to the spring, summer, and fall. SiO_4^{4-} concentrations were greater in the fall compared to the spring, summer, and winter.

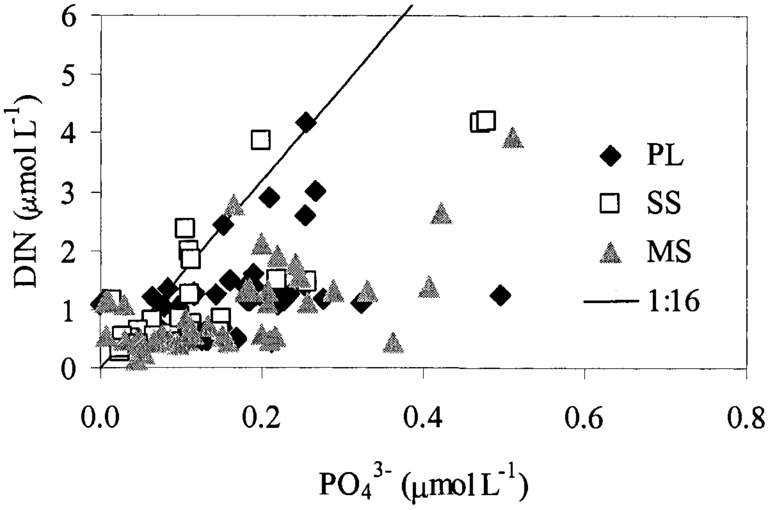

Fig. 3.11. DIN versus PO_4^{3-} concentrations for the PL, SS, and MS regions. The solid line indicates the 16:1 Redfield ratio for DIN to PO_4^{3-}.

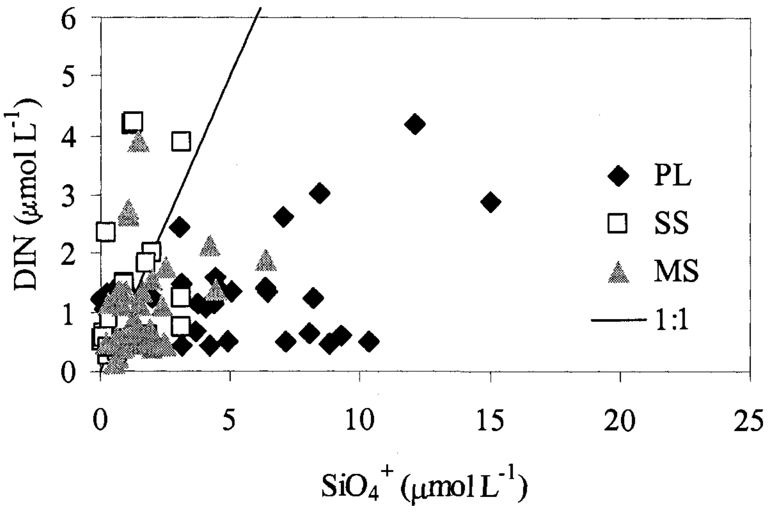

Fig. 3.12. DIN versus SiO_4^{4-} concentrations for the PL, SS, and MS regions. The solid line indicates the 1:1 Redfield ratio for DIN to SiO_4^{4-}.

PO_4^{3-} and SiO_4^{4-} concentrations did not have strong significant linear relationships between temperature and salinity for the pooled data, however during the fall, like NH_4^+, significant negative linear relationships were observed. PO_4^{3-} concentrations showed significant negative linear relationships with temperature ($R = -0.806$; $p < 0.05$) and salinity ($R = -0.735$; $p < 0.05$). Similarly, SiO_4^{4-} concentrations had significant negative linear relationships with temperature ($R = -0.764$; $p < 0.05$) and salinity ($R = -0.923$; $p < 0.05$).

BIOLOGICAL REGIME

The greatest differences in Chl *a* concentrations between D1 and D2 (12.1 and 3.1 μg chl L^{-1}, respectively) were observed in the plume in March 2005 when there was strong, fresh, surface outflow, and the water column was highly stratified (see Ch. 2; Appendix Table A.3). Aside from this one anomaly, average Chl *a* concentrations in the PL region between D1 and D2 were not significantly different ($p > 0.05$). Chl *a* concentrations overlapped between the surface and at depth in the MS region (D1: 0.2 – 2.1 μg chl L^{-1}; D2: 0.4 to 2.8 μg chl L^{-1}; Appendix Table B.3) and SS region (D1: 0.1 – 2.0 μg chl L^{-1}; D2: 0.3 to 2.2 μg chl L^{-1}), but the overall averages at D2 were significantly greater than the averages at D1 in both the MS and SS regions (ANOVA; Tukey test; $p < 0.05$). Chl *a* concentrations, when averaged for both depths among regions, were significantly greater at the PL stations, in comparison to the SS and MS stations, ranging from 0.8 to 12 μg chl L^{-1} (ANOVA; Tukey test; $p < 0.05$; Fig. 3.13). No significant relationships were observed between temperature or salinity and Chl *a* concentrations in either the SS or MS regions ($p > 0.05$) and only a weak negative linear relationship was observed between temperature and Chl *a* ($R = -0.359$; $p < 0.05$) in the PL region. When

Chl *a* concentrations were averaged over region and depth for each season, winter concentrations were significantly greater than spring, summer, and fall concentrations (ANOVA; Tukey test; $p < 0.05$; Fig. 3.14). Only significant negative linear relationships were observed during the fall between temperature and Chl *a* ($R = -0.781$) and salinity and Chl *a* ($R = -0.818$).

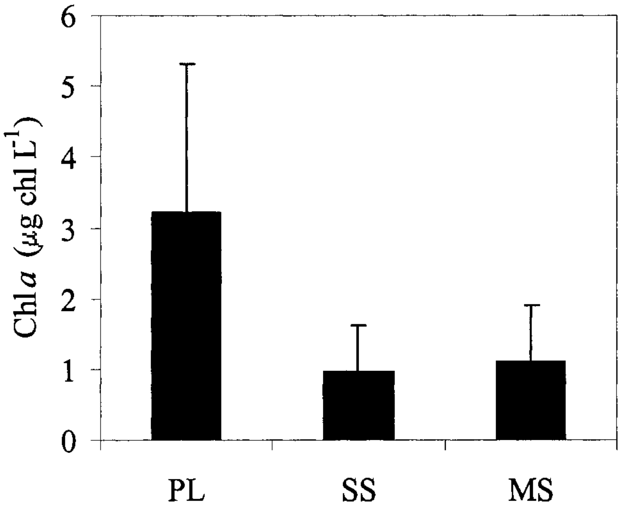

Fig. 3.13. Chl *a* concentrations averaged for each region. Chl *a* concentrations in the PL region were significantly greater than the SS and MS stations.

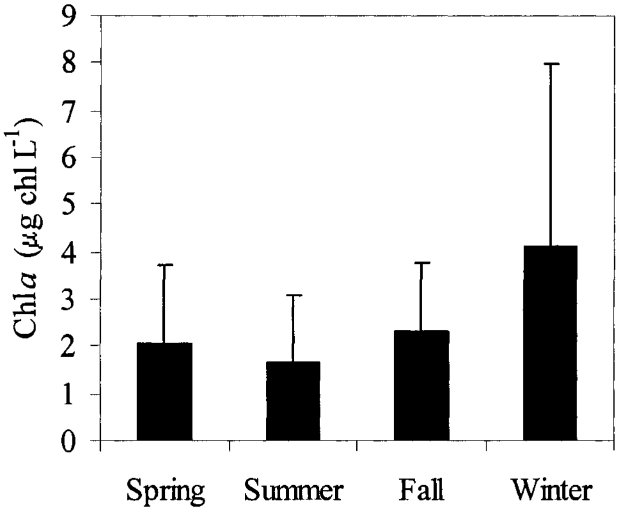

Fig. 3.14. Chl *a* concentrations averaged for each season. Chl *a* concentrations were significantly greater during winter compared to spring, summer, and fall.

Average PN and PC concentrations were not significantly different between D1 and D2 for any region ($p > 0.05$; Appendix Table B.3). Similar to Chl *a* concentrations, PN and PC concentrations were significantly greater in the PL stations compared to the SS and MS stations (ANOVA; Tukey test; $p < 0.05$; Fig. 3.15). When PN and PC concentrations were averaged for each season, there was no significant difference among seasons for PN concentrations, but PC concentrations were significantly greater in the spring compared to the fall (ANOVA; Tukey test; $p < 0.05$; Fig. 3.16). PN and PC concentrations showed significant negative linear relationships with temperature (PN: $R = -0.817$; PC: $R = -0.824$) and salinity (PN: $R = -0.841$; PC: $R = -0.812$) only during the fall. Also, however significant relationships did exist with Chl *a* concentrations for all combined data (Fig. 3.17; Appendix table B.7). The strongest relationships were observed in the MS stations, where R = 0.818 for Chl *a* versus PN and R = 0.616 for Chl *a* versus PC, followed by the PL stations where R = 0.718 for Chl *a* versus PN and R = 0.641 for Chl *a* versus PC, and in the SS stations where R = 0.639 for Chl *a* versus PN and R = 0.467 for Chl *a* versus PC.

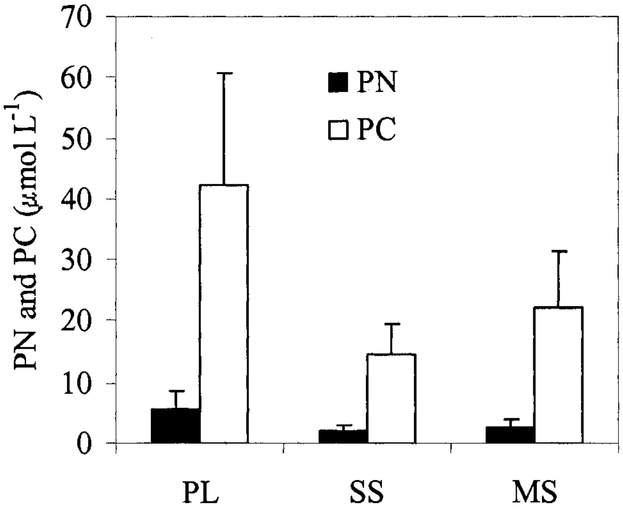

Fig. 3.15. PN and PC concentrations averaged for each region. PN and PC concentrations in the PL region were significantly greater than the SS and MS stations.

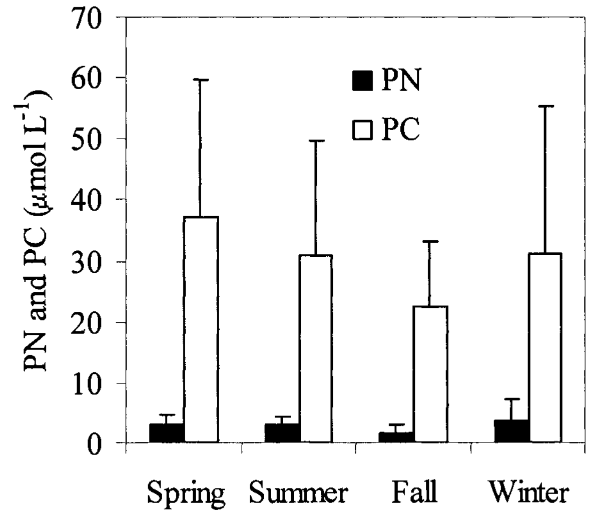

Fig. 3.16. PN and PC concentrations averaged for each season. PN concentrations were not significantly different between seasons, but PC concentrations were significantly greater in the spring compared to the fall.

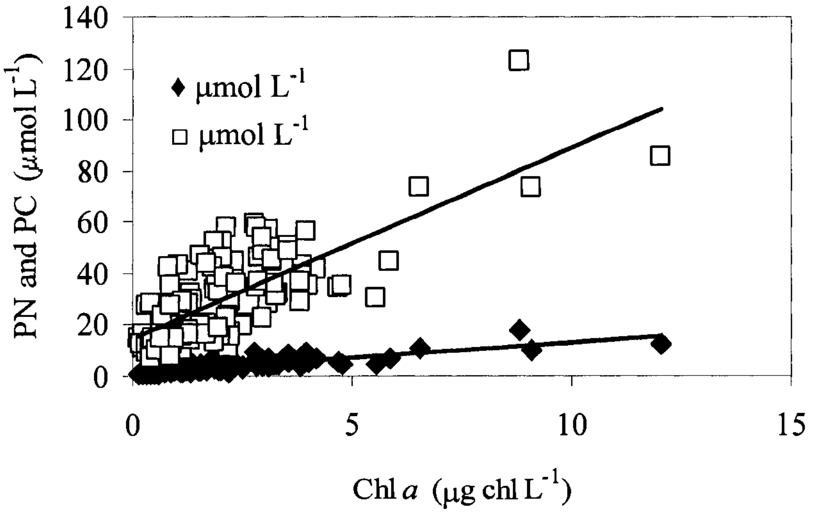

Fig. 3.17. PN and PC concentrations versus Chl *a* concentrations for all pooled data at both depths. A significant linear relationship was observed between Chl *a* and PN (R = 0.824) and PC (R = 0.761) concentrations.

C AND N UPTAKE

Primary productivity rates, both volumetric and Chl *a* normalized, are reported here as averages of both depths, as rates were not significantly different between depths for each region ($p > 0.05$; Figs. 3.18 – 3.23). Volumetric bicarbonate uptake rates were significantly greater in the PL region compared to the SS and MS regions for all combined data (ANOVA; Tukey test; $p < 0.05$), but no significant differences were observed for Chl *a* normalized primary productivity rates among regions for all data combined ($p > 0.05$). During March 2005, volumetric primary productivity rates ranged between 0.8 and 10.7 μmol C L^{-1} d^{-1} (Fig. 3.18A) and Chl *a* normalized rates ranged between 0.2 and 3.4 μmol C μg chl^{-1} d^{-1} (Fig. 3.18B).

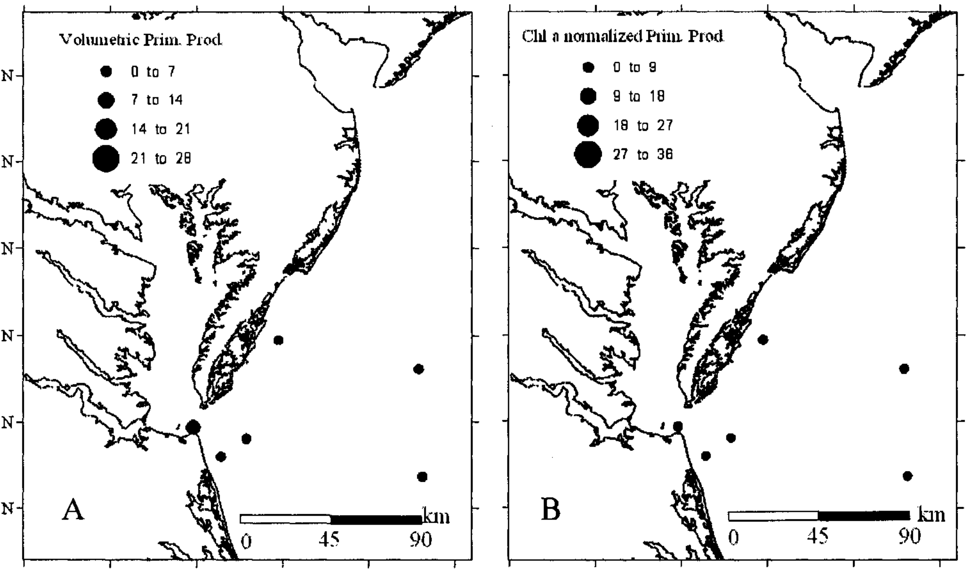

Fig. 3.18. Volumetric primary productivity rates (μmol C L^{-1} d^{-1}; A) and Chl *a* normalized primary productivity rates (μmol C μg chl^{-1} d^{-1}; B) during March 30 – April 1, 2005. Rates are averaged over surface and near bottom.

During the first summer cruise, July 2005, volumetric and Chl *a* normalized rates had the largest ranges (Volumetric: 3.5 – 27.2 μmol C L^{-1} d^{-1}; Chl *a* normalized: 5.0 – 36.2 μmol C μg chl^{-1} d^{-1}; Fig. 3.19A and B). Volumetric rates were significantly greater in the plume and coastal regions of the mid-shelf (Fig. 3.19A) while Chl *a* normalized rates were greatest along the coast and off-shore (Fig. 3.19B).

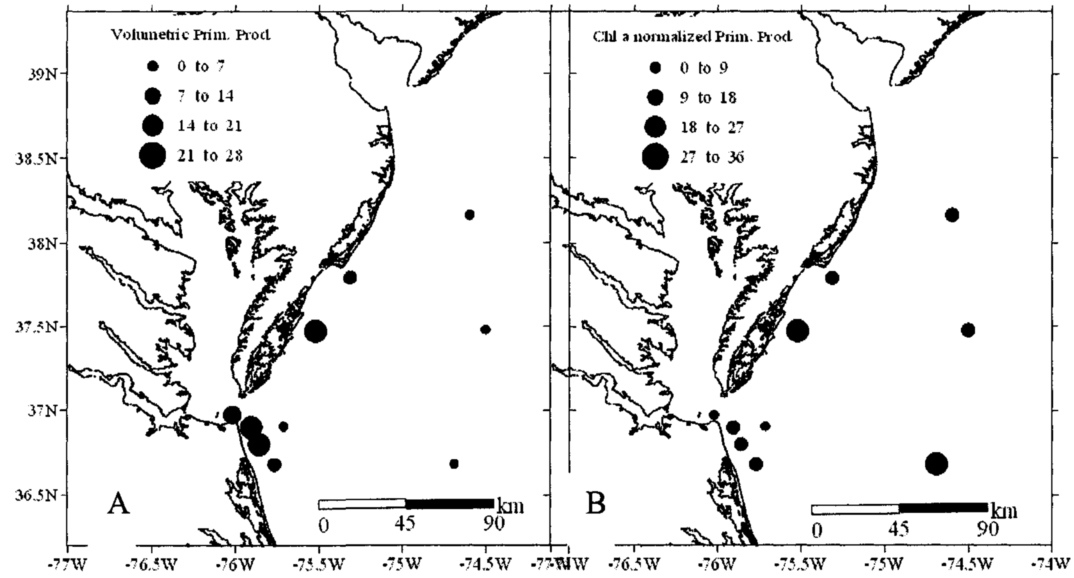

Fig. 3.19. Volumetric primary productivity rates (μmol C L^{-1} d^{-1}; A) and Chl *a* normalized primary productivity rates (μmol C μg chl^{-1} d^{-1}; B) during July 27 – 30, 2005. Rates are averaged over surface and near bottom.

During spring 2006, volumetric primary productivity rates ranged between 0.7 and 15.8 μmol C L^{-1} d^{-1} and Chl *a* normalized rates ranged between 0.4 and 7.6 μmol C μg chl^{-1} d^{-1} (Fig. 3.20A and B). Rates were uniform throughout the study area, with only slightly higher volumetric rates observed in the two plume regions (Fig. 3.20).

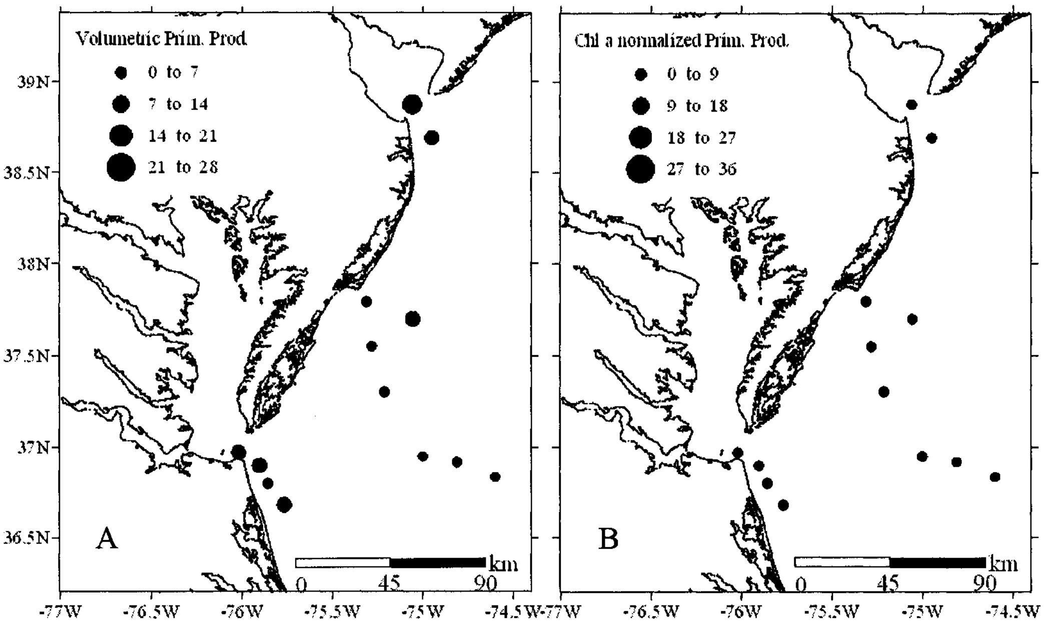

Fig. 3.20. Volumetric primary productivity rates (μmol C L^{-1} d^{-1}; A) and Chl *a* normalized primary productivity rates (μmol C μg chl^{-1} d^{-1}; B) during May 8 –12, 2006. Rates are averaged over surface and near bottom.

During July 2006, volumetric primary productivity rates were lower than the first summer cruise and ranged between 0.7 and 9.3 μmol C L^{-1} d^{-1} (Fig. 3.21A). Similarly, Chl *a* normalized rates ranged between 1.4 and 13.8 μmol C μg chl^{-1} d^{-1} (Fig. 3.21B). There were no significant differences among regions for both volumetric and Chl *a* normalized primary productivity rates.

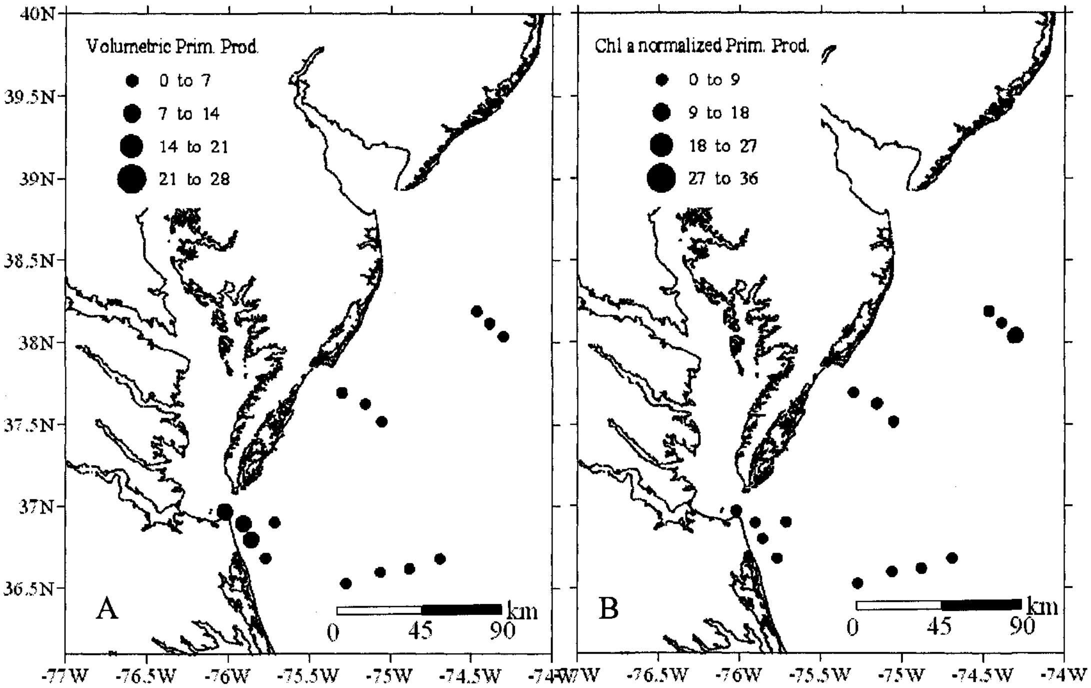

Fig. 3.21. Volumetric primary productivity rates (μmol C L^{-1} d^{-1}; A) and Chl *a* normalized primary productivity rates (μmol C μg chl^{-1} d^{-1}; B) during July 2 – July 5, 2006. Rates are averaged over surface and near bottom.

During October 2006, volumetric primary productivity rates were as low as those observed in March 2005 and ranged from 1.4 to 10.5 μmol C L^{-1} d^{-1} (Fig. 3.21A). Similarly, Chl *a* normalized rates were also as low as those observed in March and ranged between 0.9 to 4.7 μmol C μg chl^{-1} d^{-1} (Fig. 3.22B).

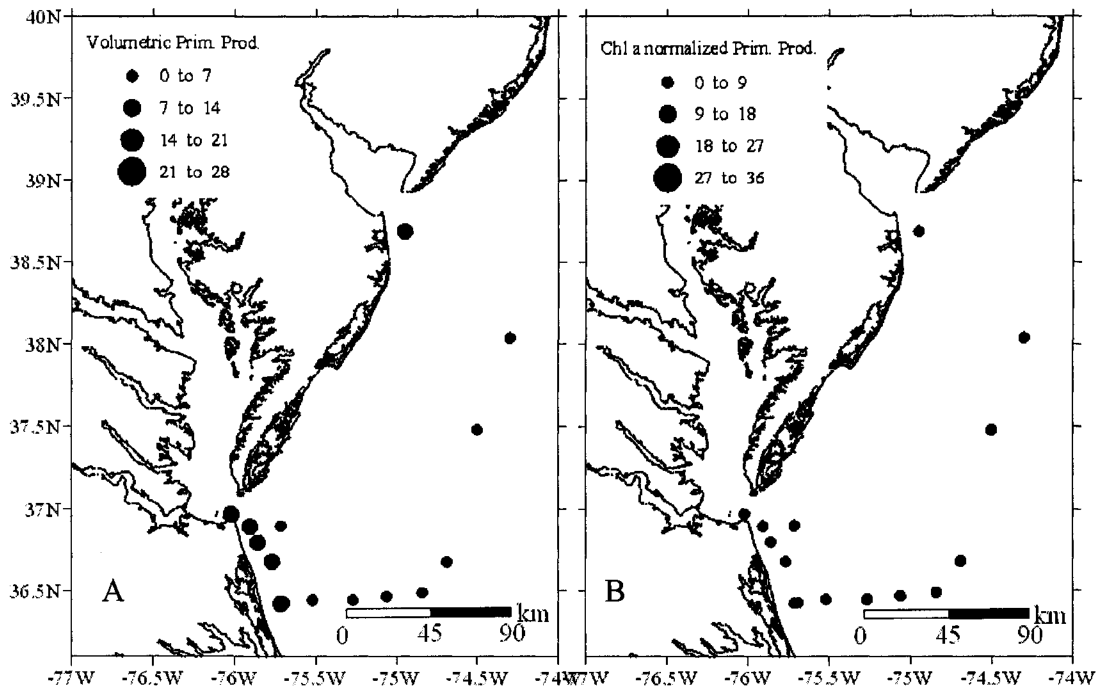

Fig. 3.22. Volumetric primary productivity rates (μmol C L^{-1} d^{-1}; A) and Chl *a* normalized primary productivity rates (μmol C μg chl^{-1} d^{-1}; B) during Oct. 30 – Nov. 2, 2006. Rates are averaged over surface and near bottom.

When volumetric primary productivity rates were averaged for each season there were no significant differences among seasons (ANOVA; $p > 0.05$; Fig. 3.23). However, Chl *a* normalized primary productivity rates were significantly greater in the summer compared to the fall and winter average rates (ANOVA; Tukey test; $p < 0.05$; Fig. 3.23).

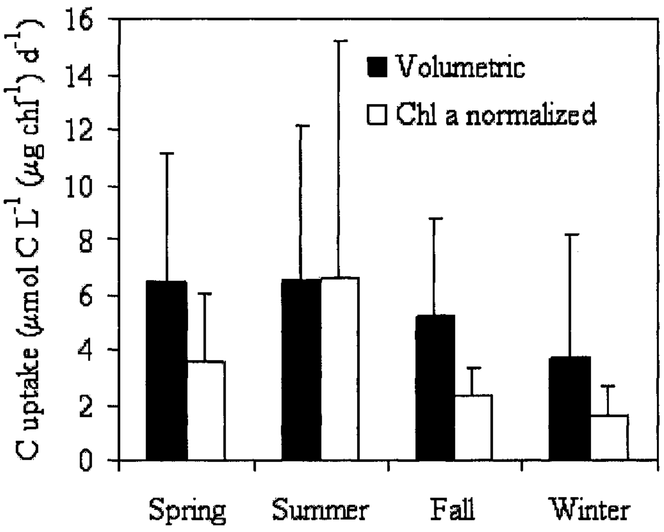

Fig. 3.23. Volumetric (solid bars) and Chl *a* normalized (white bars) primary productivity rates averaged for each season. Error bars represent standard deviations. No significant differences were observed among season for volumetric primary productivity rates, but Chl *a* normalized primary productivity rates were significantly greater in the summer compared to the fall and winter averages.

A significant positive linear relationship ($p < 0.05$) but low R value ($R = 0.367$) was observed between primary productivity rates and Chl *a* concentrations for all of the pooled data (Fig. 3.24; Appendix table B.7), similar to what was observed in the Chesapeake Bay outflow plume (Ch. 2; Fig. 2.36). When data were averaged over region, no significant linear relationships were observed between volumetric primary productivity rates and Chl *a* concentrations ($p > 0.05$). When data were averaged over season, there was a significant positive linear relationship between volumetric primary productivity rates and Chl *a* concentrations during spring ($R = 0.659$; $p < 0.05$) and the relationship was most pronounced in fall ($R = 0.882$; $p < 0.05$; Fig. 3.24).

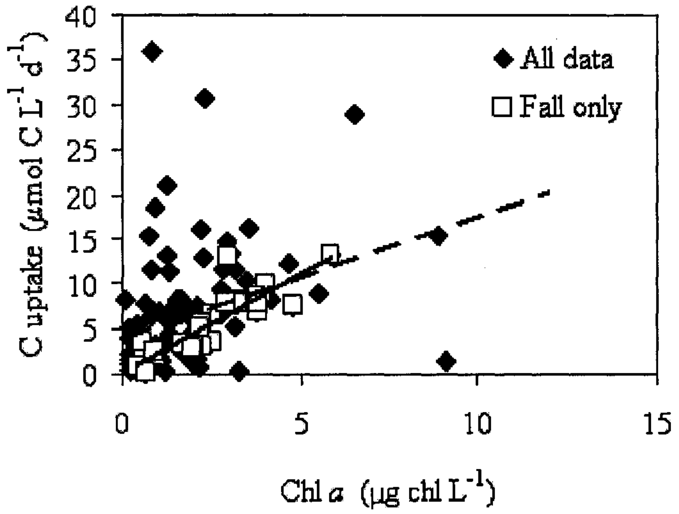

Fig. 3.24. Volumetric primary productivity rates versus Chl *a* concentrations for all pooled data and for fall only. A significant positive linear relationship was observed with a low R value for the pooled data (dashed line; R = 0.367) and a significant positive linear relationship with a high R value for the fall only data (solid line; R = 0.882).

Pooled data for volumetric primary productivity rates versus salinity showed a weak negative linear relationship ($R = -0.467$; $p < 0.05$; Appendix table B.7). The dominant signal for this relationship was found in the MS region, where there were significant negative linear relationships between salinity and volumetric primary productivity rates ($R = -0.474$; $p < 0.05$) and between salinity and Chl *a* normalized primary productivity rates ($R = -0.492$; $p < 0.05$). There was a weak positive linear relationship ($R = 0.462$; $p < 0.05$; Appendix table B.7) between Chl *a* normalized primary productivity rates and temperature for the pooled data. Similar to salinity, the dominant signal appeared in the MS region, where there were significant positive linear relationships between temperature and volumetric primary productivity rates ($R = 0.466$;

$p < 0.05$) and temperature and Chl *a* normalized primary productivity rates ($R = 0.629$; $p < 0.05$).

During fall, when there was a significant positive linear relationship between volumetric primary productivity rates and Chl *a* concentrations, there was a significant negative linear relationship between salinity and volumetric primary productivity rates ($R = -0.794$; $p < 0.05$). Furthermore, there was a significant negative linear relationship between temperature and volumetric primary productivity rates in the fall ($R = -0.728$; $p < 0.05$; Fig. 3.25), however in this case, it was a negative linear relationship. During the fall, negative linear relationships between salinity and temperature, and volumetric primary productivity rates signified that in cool (15°C), fresher (24) waters, volumetric primary productivity rates were high and in warm (24°C), salty (36) waters, volumetric primary productivity rates were low (Fig. 3.25). Also in the fall, significant negative linear relationships were observed between temperature and Chl *a*, PN, PC, NH_4^+, PO_4^{3-}, and SiO_4^{4-}. The physical regime is consistent with fall satellite imagery (Fig. 3.4) depicting cool water exiting the Bay mouth, presumably providing nutrient-rich freshwater available for uptake by primary producers into the coastal zone. The relationship between primary productivity and nutrient availability was further demonstrated by the significant positive linear relationships observed between volumetric primary productivity rates and TDN concentrations ($R = 0.634$; $p < 0.05$), PO_4^{3-} concentrations ($R = 0.649$; $p < 0.05$), and SiO_4^{4-} concentrations ($R = 0.759$; $p < 0.05$) in the fall.

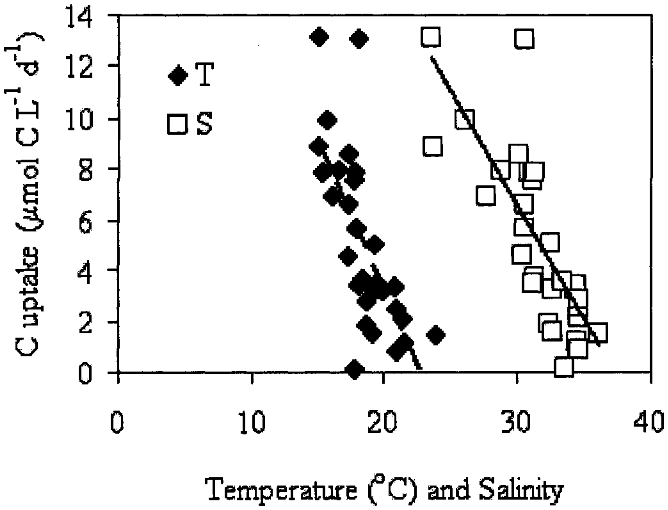

Fig. 3.25. Volumetric primary productivity versus temperature and salinity for the fall. Volumetric C uptake was significantly related to temperature (dashed line; R = 0.728) and salinity (solid line; R = 0.794).

Similar to primary productivity results, there were no significant differences between total N uptake rates at either depth, therefore rates reported here are averages of both depths. Also similar to primary productivity results, total measured volumetric N uptake rates were significantly greater at the PL region (0.01 – 0.63 μmol N L^{-1} h^{-1}; Appendix table A.5). Specifically, NH_4^+ volumetric uptake rates were significantly greater in the PL region compared to the SS and MS regions, and NO_3^-, urea, and DFAA N volumetric uptake rates were significantly greater in the PL region compared to the SS region (Fig. 3.26). At the MS stations, total N uptake rates ranged from 0.01 – 0.54 μmol N L^{-1} h^{-1} (Fig. 3.26; Appendix table B.5). The lowest N uptake rates were observed at SS stations (0.01 – 0.23 μmol N L^{-1} h^{-1}; Fig. 3.26; Appendix table B.5).

Although total N uptake rates were greatest in the PL region, where Chl *a* biomass was also highest (Fig. 3.13) compared to the MS and SS regions (Fig. 3.26), total N uptake rates did not significantly correlate to Chl *a* concentrations in the PL region ($p > 0.05$). There was no significant linear relationship between Chl *a* and total N uptake or between Chl *a* and individual N compound uptake rates ($R = 0.056$; $p > 0.05$; Fig. 3.27) for the pooled data. N uptake was fairly constant over a range of Chl *a* concentrations, for example, NH_4^+ uptake rates were nearly identical (0.34 and 0.35 µmol N L^{-1} h^{-1}) at PL stations within Chl *a* concentrations of 2.2 and 9.1 µg chl L^{-1}, respectively.

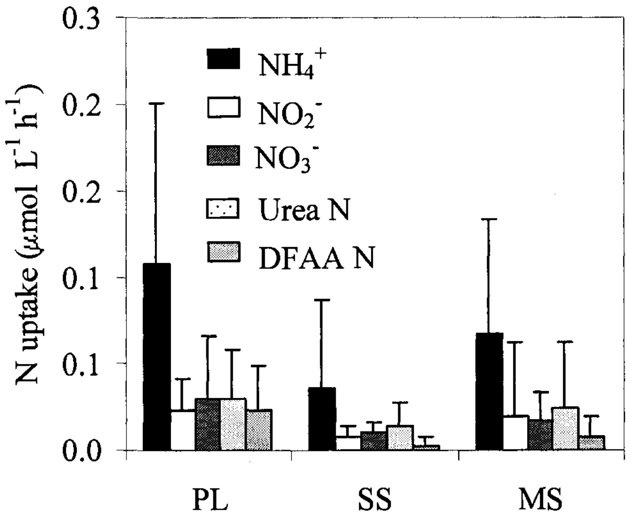

Fig. 3.26. N uptake rates averaged for each region. Total N uptake rates were significantly greater in the PL region compared to the SS or MS regions.

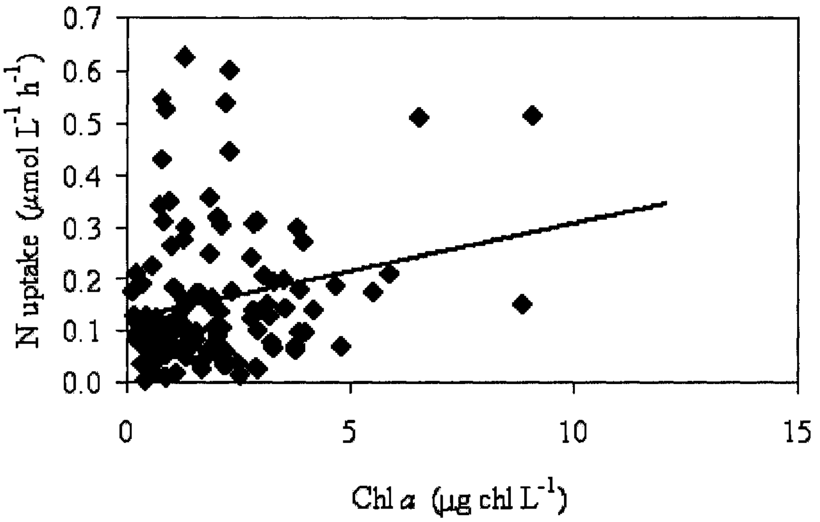

Fig. 3.27. Total N uptake rates versus Chl *a* concentrations for all pooled data. No significant relationship was observed.

Total N uptake rates were significantly greater in the summer compared to the fall, specifically for NH_4^+ and urea uptake rates (Fig. 3.28). DFAA N uptake rates were significantly greater during winter compared to spring, summer, and fall (Fig. 3.28). No significant differences were observed among seasons for NO_3^- and NO_2^- volumetric uptake rates (ANOVA; $p > 0.05$).

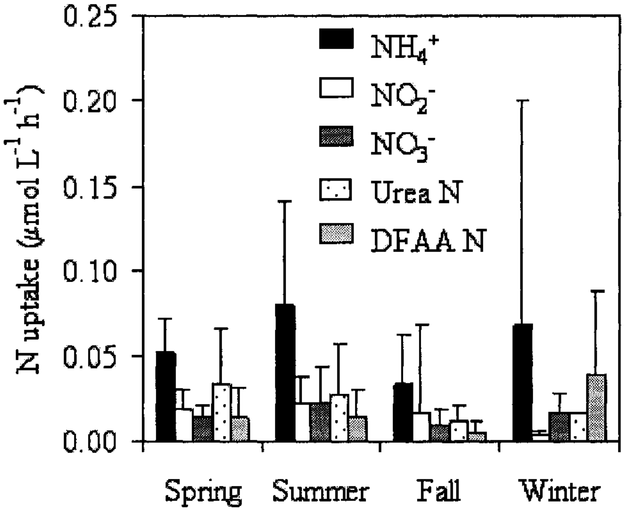

Fig. 3.28. N uptake rates averaged for each season. Error bars represent standard deviation. Total N uptake rates were significantly greater in the summer compared to the fall.

NH_4^+ uptake rates on average were significantly greater (ANOVA; Tukey test; $p < 0.05$) than uptake of the other N compounds measured and often represented over 50% of the total measured N uptake. In a few instances, however, in offshore stations in the SS region, uptake rates of NO_3^- (0.013 – 0.029 µmol L^{-1} h^{-1}) were greater than uptake rates of NH_4^+ (0.002 – 0.007 µmol L^{-1} h^{-1}).

Relationships between individual nutrient concentrations and ^{15}N uptake rates (volumetric, Chl *a* normalized, and PN normalized), results were inconsistent. Although NH_4^+ was taken up at higher rates than any other N compound, there was no significant relationship between NH_4^+ concentrations and volumetric ($R = 0.213$; $p > 0.05$; Appendix table B.7), Chl *a* normalized ($R = 0.124$; $p > 0.05$; Appendix table B.7), or PN normalized ($R = 0.169$; $p > 0.05$; Appendix table B.7) NH_4^+ uptake rates for the pooled data. Similarly, no significant relationships were found when correlating nutrient concentrations versus volumetric, Chl *a* normalized, or PN normalized uptake rates of NO_2^-, NO_3^-, and urea for the pooled data (Appendix table B.7). Volumetric DFAA N uptake rates did show a weak, but significant positive linear correlation with DFAA N concentrations for the pooled data ($R = 0.469$; $p < 0.05$; Appendix table B.7).

Either no significant relationships or only weak significant relationships between nutrient concentration and ^{15}N uptake rates were also observed regionally. For NH_4^+ in the SS region, a weak but significant positive linear relationship between NH_4^+ concentrations and volumetric NH_4^+ uptake rates ($R = 0.417$; $p < 0.05$) was observed. The only significant relationship with an R value greater than 0.5 in the PL region was observed for DFAA N concentrations versus DFAA N volumetric uptake rates ($R = 0.575$; $p < 0.05$). In the MS region, either no significant relationships, or only weak significant relationships were observed for NH_4^+, NO_2^-, and NO_3^- concentrations versus volumetric, Chl *a* and PN normalized uptake rates. There were significant positive correlations in the MS region for urea and DFAA N, however. Urea concentrations versus volumetric ($R = 804$; $p < 0.05$), Chl *a* normalized ($R = 0.598$; $p < 0.05$), and PN normalized ($R = 0.759$; $p < 0.05$) urea uptake rates and DFAA N concentrations versus DFAA N volumetric ($R = 0.857$; $p < 0.05$), Chl *a* normalized ($R = 689$; $p < 0.05$), and PN normalized ($R = 0.777$; $p < 0.05$) DFAA N uptake rates had significant positive linear relationships.

Seasonally, relationships between nutrient concentrations and nutrient uptake rates were also inconsistent and weak. During spring, either no significant relationships or weak significant relationships were observed between nutrient concentrations and their respective uptake rates (volumetric, Chl *a* normalized, or PN normalized) for all nutrients. During summer, NH_4^+ concentrations versus volumetric NH_4^+ uptake rates showed a significant positive linear relationship ($R = 0.636$; $p < 0.05$). Also during summer, significant positive linear relationships between urea concentrations and urea volumetric ($R = 0.840$; $p < 0.05$), Chl *a* normalized ($R = 0.691$; $p < 0.05$), and PN normalized ($R = 0.822$; $p < 0.05$) uptake rates. Similarly, significant positive linear relationships were observed for DFAA N concentrations and volumetric ($R = 0.580$; $p < 0.05$), Chl *a* normalized ($R = 0.627$; $p < 0.05$), and PN normalized ($R = 0.754$; $p < 0.05$) DFAA N uptake rates in the summer. During the fall, only urea concentrations had a significant linear correlation with volumetric urea uptake rates ($R = 0.625$; $p < 0.05$). During winter, no significant relationships were observed between nutrient concentrations and nutrient uptake rates (volumetric, Chl *a* normalized, or PN normalized).

DISCUSSION

The hydrographic regions identified in this study differentially impact C and N pools and primary productivity rates in the MAB. The Chesapeake Bay plume region is highly productive, but the delivery of nutrients and particulate material is extremely sensitive to time varying flow and periodic storm events (see Ch.2). In addition, the plume region and nearby shelf regions can be influenced by oceanic inputs of upwelled nutrients and warm oligotrophic Gulf Stream waters. Because the MAB is thought to be

N-limited (Dugdale 1967; Ryther and Dunstan 1971), inputs of bioavailable N to coastal waters and the continental shelf can alleviate N limitation and stimulate primary productivity resulting in greater fisheries yields, however too much N can lead to coastal eutrophication and water quality degradation.

In Chapter 2, I demonstrated that the extent to which the plume interacts with coastal waters can depend on winds, freshwater discharge, and local upwelling or downwelling events and that the type of plume can be a factor influencing productivity (see Ch. 2). Here, I observed that the near shore regions north of the Chesapeake Bay plume, were also influenced by oceanic upwelling as well as terrestrial inputs, and in the mid-shelf region nutrient concentrations and Chl *a* normalized primary productivity rates could be equal to or greater than concentrations and rates in the plume region. Primary productivity in the MAB was supported by a diverse array of N compounds and the importance of any one form of N varied by location. For example, although NH_4^+ was the dominant form taken up, there were instances where NO_3^- uptake dominated, presumably due to upwelling at offshore stations. In oligotrophic, oceanic systems, upwelled NO_3^- and N_2 fixation are considered the primary N sources supporting new production (Dugdale and Goering 1967), and in the MAB region, upwelled N was observed primarily at offshore stations located near the shelf break. Also, it appeared for the most part, that N uptake rates were not dependant on nutrient concentrations, in this environment, similar to what was observed for the plume region (see Ch. 2).

This study provides seasonally resolved primary productivity and N uptake rates over a two year period in the context of the physical and nutrient environment and a regional overview of N and C dynamics and budgets for the MAB. To put these results into a broader context, I calculated areal rates of primary productivity and N uptake by converting daily rates, made over three seasons, and two years, to annual estimates for each region. Average areal C and N uptake rates were not significantly different among regions presumably due to the shallow water column at highly productive plume stations (Table 3.1). These annual areal primary productivity rates at the Gulf Stream-influenced SS stations were lower than published estimates of primary productivity in Gulf Stream intrusions (54 ± 20 mol C m^{-2} y^{-1} spring and summer; Tables 3.1 and 3.2) (Mouw and Yoder 2005). The overall average annual primary productivity for the study region was 34 ± 3.8 mol C m^{-2} y^{-1} and areal N uptake was 11 ± 2.1 mol N m^{-2} y^{-1}. There were no significant differences among seasonal averages for areal primary productivity for the pooled data, however rates in the summer were as high as 0.38 mol C m^{-2} d^{-1} and 0.25 mol C m^{-2} d^{-1} in the spring when fall and winter rates were only as high as 0.12 mol C m^{-2} d^{-1} and 0.19 mol C m^{-2} d^{-1}, respectively. Summer areal N uptake rates were significantly greater than the spring and fall rates. When applying areal rates (mol m^{-2} y^{-1}) over the surface area of each respective region, annual primary productivity and total N uptake rates (mol y^{-1}) were 3.4 and 4.2 times greater, respectively, in the MS area than in the PL and SS regions, combined (Table 3.1).

Table 3.1. Summary table of surface area of each hydrographic regime calculated from cruise maps, average euphotic depth, daily volumetric primary productivity rates based on 12 or 24 hours of uptake, daily total N (TN) uptake rates based on 12 hours of uptake, areal primary productivity rates calculated from the depth of the euphotic zone and averaged over surface and fluorescence maximum, and integrated seasonally, areal total N uptake rates calculated similarly to areal primary productivity, annual C uptake due to primary productivity, annual total N uptake, and annual C:N uptake ratios. Values are averages of all stations for each region across all seasons for both years and surface and fluorescence maximum rates with ranges in parentheses.

	Surface Area km^2	Euphotic depth m	Daily primary productivity $\mu mol\ C\ L^{-1}\ d^{-1}$	Daily TN uptake $\mu mol\ N\ L^{-1}\ d^{-1}$	Areal primary productivity $mol\ C\ m^{-2}\ y^{-1}$	Areal total N uptake $mol\ N\ m^2\ y^{-1}$	Annual C uptake $mol\ C \times 10^9\ y^{-1}$	Annual N uptake $mol\ N \times 10^9\ y^{-1}$	Annual C:N uptake
PL	1200	12	9.3 (0.5 – 30.6)	2.6 (0.2 – 7.5)	37.4 (12.7 – 68.6)	11.3 (3.3 – 21.5)	45 (15 – 82)	14 (4.0 – 26)	3.3
SS	6300	38	2.6 (0.5 – 8.3)	1.0 (0.1 – 2.7)	30.0 (5.0 – 38.8)	8.7 (3.5 – 11.9)	189 (32 – 245)	55 (22 – 75)	3.5
MS	22450	27	5.3 (0.2 – 36.0)	1.6 (0.2 – 6.5)	35.4 (12.0 – 71.3)	12.9 (5.7 – 20.9)	794 (270 – 1600)	289 (128 – 469)	2.7
Total	29950						1030 (317 – 1930)	358 (154 – 569)	

Areal C uptake rates in the MAB calculated here and including three distinct hydrographic regions were similar to but often exceeded those reported in the literature from a variety of field programs implemented between the early 1970's and the early 1990's (Table 3.2) suggesting that primary productivity in the MAB may have increased over the last 10 to 40 years. This could be due to the fact that primary productivity is actually increasing over time due to increased nutrient inputs (Fig. 3.29). There is a trend upward from measurements made over the past 20 years (Fig. 3.29; Table 3.2). The outliers aren't shown as they come from the South Atlantic Bight where productivity is known to be higher than the MAB (O' Reilly and Busch 1984; Lohrenz et al. 2002; Verity et al. 2002). Alternatively, estimates presented here are better resolved than previous estimates, as they are *in situ* estimates from 4 seasons and three hydrographic regions. Annual areal rates of productivity reported here for all three regions were significantly greater than areal estuarine productivity rates estimated from estuaries around the world (Boynton et al. 1982), and areal rates for all three regions were greater than modeled estimates for the MAB (Kemp et al. 1994; Fennel et al. 2006). Past research endeavors, like those documented in Table 3.2, have extrapolated rates based upon one or two seasons of high productivity, whereas the annual rates reported from this study included multiple seasons and regions over two years (see Table 3.2), providing for a more robust analysis of productivity, especially since the highest rates for both C and N were observed in the spring and summer. Averaged spring and summer areal estimates, extrapolated to annual estimates, were 19% greater than averaged annual estimates from all dates from this study. Higher productivity rates were observed by Lohrenz et al. (2002) in the South Atlantic Bight, again based on modeled results, where annual rates were extrapolated from only spring and summer, thus potentially overestimating annual rates (Table 3.2).

One could argue that there are very few actual measurements of productivity made in this region, so many estimates are modeled or inferred from satellite data and predicted relationships between nutrients and productivity. For example, primary productivity rates reported by Mouw and Yoder (2005) were slightly lower than what was observed in this study, but multiple sources of data over different time periods were used to obtain these estimates. Temperature data was collected to obtain the mixed layer depth during the 5-year period in question, phytoplankton community and Chl *a* data were obtained from a previous 12-year study (1977 – 1988), and nitrate concentrations were obtained from the World Ocean Atlas 2001 to implement into their productivity model (Mouw and Yoder 2005). This modeled, water-column-derived, productivity data was then compared to productivity obtained from algorithms derived from PAR and Chl *a* using SeaWiFS satellite imagery for the 5-year study period and it was determined that the satellite-derived photosynthesis rates were 30% less than water column-derived photosynthesis rates (Mouw and Yoder 2005). A daily average was multiplied by 365 d and did not take into account seasonal variations. Multiple assumptions were made, one in particular stated that nutrient availability and therefore the quantum yield of photosynthesis, was a function of nitrate concentration (Mouw and Yoder 2005). Data presented here demonstrate that nutrient availability and uptake is not a function of only nitrate concentrations in the MAB, and furthermore, primary productivity was significantly related to TDN concentrations only during the fall months. Combined, these results suggest we need more observations and direct measurement of C and N productivity to validate models and make them realistic for the region. Specifically, productive coastal regions like the Chesapeake Bay outflow plume, may be areas that can be easily targeted for further incubations studies to assess the short-term variability of N uptake, as little is known in this regard and meteorological conditions on a short timescale appear to be the driver for nutrient delivery and subsequent C and N uptake (See Ch.2). The First State of the Carbon Cycle Report (SOCCR), a recent study headed by international scientists, concluded that there is little known regarding the C budget in the coastal regions of North America and that scientists are encouraged to study the region experimentally with processed-based studies such as the one provided here (Chavez et al. 2007).

Table 3.2. Summary table of areal rates of primary productivity from the literature including a description of the study area, areal rate, and method and source for each estimate.

Study area	Areal rates of primary productivity mol C m^{-2} y^{-1}	Methods	Reference
PL	37.4 ± 11.9	^{13}C bicarbonate incubations	This study
SS	30.0 ± 4.7		
MS	35.4 ± 12.1		
Estuarine (45 estuarine systems)	15.8 ± 4.2	Multiple methods	(Boynton et al. 1982)
MAB	17	3-dimensional biogeochemical model	(Fennel et al. 2006)
New Jersey coast to Bermuda:		Productivity model using in situ data, satellite imagery, previously published data, and photosynthesis/irradiance relationship over 33.4 km^2 study areas, depth integrated. Data shown is a range for the 5-year study period of a hybrid of water column/satellite -derived productivity.	(Mouw and Yoder 2005)
Shelf	18.9 ± 0.7		
Shelf break	15.9 ± 2.8		
Slope	16.9 ± 0.6		
Gulf Stream	25.2 ± 2.0		
(5-year model with monthly averages)			
MAB	12	Model	(Kemp et al. 1994)
Spring and summer Cape Hatteras Shelf (spring and summer estimates, extrapolated for the year, and the whole region)	28	^{14}C bicarbonate incubations, depth integrated	(Redalje et al. 2002)
Cape Hatteras Shelf (spring and summer estimates, extrapolated for the year, and the whole region)	54 ± 20 30 ± 22	Wavelength resolved photosynthesis-irradiance model *In situ* estimates (n=7)	(Lohrenz et al. 2002)

Table 3.2. Continued.

Study area	Areal rates of primary productivity mol C m-2 y-1	Methods	Reference
Chesapeake Bay to Cape Hatteras, offshore-onshore	<22 - 42	Coastal Zone Color Scanner imagery	(O' Reilly et al. 1987)
South Atlantic Bight (3-yr study over summer and winter)	50 - 58	Dilution experiments, estimation via Chl *a*	(Verity et al. 1993)
Northwestern Atlantic Shelf	26	Productivity model	(O' Reilly and Busch 1984)
Atlantic Ocean (assume surface area of 77 * 10^{12} m^2)	12.6	General Circulation Model from satellite imagery	(Carr et al. 2006)
Northeast Pacific – coastal estimate	20.8	^{14}C bicarbonate incubations	(Martin et al. 1987)
Northeast Pacific – oceanic estimate	10.8 ± 2.9	^{14}C bicarbonate incubations	(Martin et al. 1987)
Global continental shelf (40 different regions; 70% of global continental shelf)	18	Average of 40 different studies	(Walsh 1988)
Global continental shelf	16.7 – 18.3	Average estimates	(Wollast and Billen 1981; Wollast 1991)

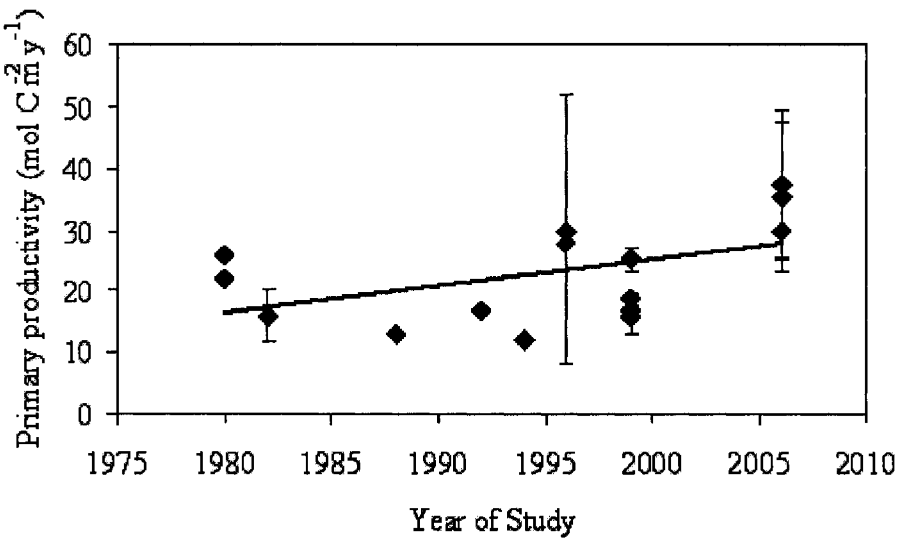

Fig. 3.29. Primary productivity rate estimates in the MAB over time. The estimates are obtained from Table 3.2 and include only rates from the MAB. The most recent rates are from this study, an increasing trend is shown.

The ratio of areal annual primary production to total N uptake ranged from 2.7:1 to 3.5:1, much lower than that expected using the Redfield ratio of 6.6 (Table 3.1). This low ratio suggests that C productivity and N uptake were not tightly coupled on short timescales. This could be due to imbalanced growth, underestimates of C uptake, or overestimates of autotrophic N uptake on GF/F filters. If only DIN uptake was considered, C:N uptake ratios increased slightly to 3.6 – 4.7:1, but still below 6.6. The canonical Redfield ratio has been used to calculate either C or N uptake, one from the other, and removal for model simulations and in generic interpretations for large scale studies of C and N budgets (Seitzinger and Giblin 1996; Fennel et al. 2006). This study suggests that using Redfield assumptions for short timescales of variability may underestimate N uptake based on primary productivity measurements or overestimate C drawdown based on measured N uptake rates, but Redfield is still an adequate assumption when extrapolating to global scenarios and long timescales. However, N uptake rates from previous studies, and model simulations use only DIN uptake, specifically NO_3^-, to infer net C uptake (Mouw and Yoder 2005; Fennel et al. 2006). For this study, the average ratio of hourly primary productivity to NO_3^- uptake was much greater than 6.6 (PL: 34 ± 50, SS: 12.5 ± 8.2, MS: 42 ± 84). Prior research in the plume reported hourly primary productivity rates to NO_3^- uptake rates ranging from 0.9 – 276, again showing a wide range in variability for short-term C:N uptake studies (Malone and Ducklow 1990; Glibert and Garside 1992). In the northeastern Atlantic, during a diatom bloom, C:N ratios were close to Redfield (6-8) during low productivity, dropped below 5 when productivity increased, and rose to 17 when N became limited and the authors suggested that utilizing Redfield on timescales shorter than a month may not be approrpriate(Bury et al. 2001). The above assumptions, using only DIN or NO_3^- uptake rates or concentrations, may have biased estimates of C uptake rates from N uptake rates upwards. We now know that phytoplankton and bacteria compete for both inorganic and organic N sources in nature (Mulholland and Lomas 2008). With increasing anthropogenic N, these relationships are only going to continue to change and great care must be taken in determining primary production from N when there is no clear defining relationship, particularly in the coastal waters of the MAB.

Although not the main focus of this research, pCO_2 concentrations were calculated (see Eqns. 3.1 – 3.4) at stations occupied during this study and they showed an undersaturation of CO_2 relative to the atmosphere in surface waters throughout the study area (Table 3.3). Surface water concentrations were lower but not significantly different than previously published values for the MAB, where the middle shelf ranged between 150 to 620 μatm, the inner shelf ranged between 220 and 480 μatm, and the outer shelf ranged between 300 and 430 μatm (De Grandpre et al. 2002). pCO_2 concentrations from this study were not significantly different between the PL, SS, and MS. Undersaturation of the MAB with respect to CO_2 is consistent with the most recent C research done for the MAB, showing that this region is a sink for atmospheric CO_2 (De Grandpre et al. 2002). However, there is a general consensus that the North American coastal systems are neither a sink or a source of atmospheric CO_2 on average, but not enough data is available to track historical trends (Chavez et al. 2007). Although not apparent from the low C:N uptake ratios, taken on small timescales, anthropogenic N inputs may fuel excess productivity allowing additional drawdown of atmospheric CO_2 in this region, and possible removal of anthropogenic C to coastal sediments where it can fuel denitrification, export to the coastal ocean, or export to the deep ocean, all important C sinks (De Grandpre et al. 2002).

Table 3.3. pCO_2 estimates from DIC, alkalinity, salinity and temperature as calculated from Eqns. 3.1 – 3.4.

Region	pCO_2 (μatm)	+/-
PL	204	154
SS	65	46
MS	139	69

It is not known whether the coastal MAB is a source or sink for anthropogenic C and N (Chavez et al. 2007). If increased total N loads or increased atmospheric CO_2 cause an increase in net primary productivity, as was potentially observed from this data set (Table 3.2; Fig. 3.29) (although the reason for the increase is not clear), and daily sedimentary denitrification rates remain 2% of primary productivity rates (e.g. Seitzinger and Giblin 1996) then N might accumulate in the MAB sediments or thereby alleviating

N limitation or resulting in the accumulation of organic material leading to coastal anoxia such as has been observed north on the MAB shelf of NJ (Glenn et al. 2004; Frazer et al. 2006). Alleviating N limitation might shift the system toward limitation by another element in short supply. However, if denitrification rates increase commensurable with increased productivity thereby maintaining an N-limited coastal system, then anthropogenic N inputs can be counterbalanced with N losses through denitrification. If primary productivity decreases in the future (something that was not observed in this data set) due to global climate change, denitrification might decrease due to C limitation of denitrifying microbes as less organic material is delivered to the sediments (Fulweiler et al. 2007).

Based on a 2 % removal rate (Seitzinger and Giblin 1996), I calculate that the total N losses through denitrification for these three hydrographic regimes was 1.1×10^{10} mol N y^{-1}, which is 11 times lower than rates estimated from the region extending from Cape Hatteras to South Florida (11.7×10^{10} mol N y^{-1}) and represents < 1% of the denitrification estimated for the entire North Atlantic Shelf (143×10^{10} mol N y^{-1}; Seitzinger and Giblin 1996). N removal from the MAB via denitrification is an important process and recent modeled estimates determined that 90% of DIN and PN entering the North Atlantic is ultimately lost from the sediments via denitrification (Fennel et al. 2006). A decrease in denitrification rates would result in retention of N in the system, where it could stimulate additional primary productivity, providing a positive feedback scenario (Fulweiler et al. 2007).

N and C dynamics are affected by not only the physical and biological environments, but also human impacts on both short and long timescales. Although satellite imagery is becoming a widely used tool to relate surface productivity with remotely sensed parameters, present and past results suggest that satellite data should be interpreted carefully and validation with measurements is necessary, as productivity rates do not always correlate well with Chl *a* biomass and there are differences in productivity with depth that may not be related in a predictable way to biomass estimates (Hoffman et al. 2008). Further, nutrient concentrations (e.g. NO_3^-) are not good predictors of productivity. The results from this study suggest that primary productivity in the MAB may be increasing or that rates reported here are more robust relative to rates reported directly or modeled using data collected 20 to 40 years ago. Long-term trends in productivity due to coastal eutrophication and large scale indices of climate change variables, such as the North Atlantic Oscillation and El Niño Southern Oscillation, are only beginning to be observed in data records and our short satellite record is not yet sufficient to observe the full extent of these trends. Additionally, coastal algorithms relating primary productivity and ocean color are not yet good enough to evaluate productivity in marine coastal waters due to instrumentation interferences, the lack of robust validation, and direct measurements (Hoffman et al. 2008). Our observations have shown that coastal productivity is important and is higher than previously estimated or is increasing at these interfaces. Equally important, better relationships between primary productivity and N uptake rates need to be elucidated to reconcile global C and N budgets, and to offer better ways to extrapolate one from the other. Resolving these issues in the coastal zone is crucial for validation of biogeochemical models that are necessary for a whole ecosystem approach to understanding the N and C dynamics and a region strongly affected by climate change.

CHAPTER IV

SUMMARY AND FUTURE DIRECTIONS

SUMMARY

In this dissertation, I present data that can provide seasonally resolved snapshots of nutrient concentrations, biomass concentrations, N uptake rates, and primary productivity rates in the plume and receiving waters for the largest estuary in North America, and spanning a three year period. Rates of N uptake and primary productivity in the Chesapeake Bay plume were compared with rates measured in the adjacent coastal ocean, including the shelf area north of the Chesapeake Bay mouth and an area of the shelf often impacted by the Gulf Stream. All concentrations as well as rate measurements were reviewed in the context of freshwater flow, water column mixing, and wind dynamics. This research was motivated by prior modeling efforts and will advise future efforts, such as that proposed by the U.S. east coast continental shelf project team, to model the regional and global C budgets (Hoffman et al. 2008). Further, the results presented in this dissertation were used by NASA scientists to reconcile satellite imagery and ocean color with C pools and cycling in the coastal ocean.

The major findings of this research are:

- Primary productivity does not correlate with Chl *a* concentrations in a coastal system dominated by physical processes.
- Plume morphotypes were important in determining biomass versus productivity relationships; low flow conditions promoted *in situ* productivity while high flow, or 'wash out' conditions promoted high biomass exported from the Bay.

- N concentration was a poor predictor of N uptake, and inorganic and organic forms of N are important for understanding total N uptake demands.
- Primary productivity rates may be increasing over time in the MAB, or our analyses may simply be more robust, incorporating direct measurements and season variability.
- The Redfield ratio can not be used to interpret regional N demand from C uptake and vice versa.

The ocean is the largest planetary C sink and so how the oceanic environment will respond to higher C concentrations is a subject of intense debate. Further, the coastal ocean is an area increasingly impacted by anthropogenic N inputs. The combined impacts to marine systems from climate change superimposed on eutrophication are unknown (see Galloway et al. 2008). Characterizing the impact of the Chesapeake Bay on coastal productivity is an important step in our understanding of C dynamics in a region dominated by anthropogenic influences. Because there are productivity estimates from almost 40 years ago, we can speculate as to long term trends in productivity in this area (see Fig. 3.29). This project was a large undertaking, and although the temporal resolution was robust, it was clear from the beginning that a complete understanding of the MAB and the Chesapeake Bay outflow plume in terms of N and C was not going to be achieved in a three-year study even with monthly or seasonally allocated field measurements. This study however was an improvement over many previous studies in the fact that it spanned 3 years, 4 seasons, and 3 types of hydrographic regimes, allowing for a more robust analysis of areal N uptake and primary productivity.

Seasonal variations in nutrient cycling and carbon biogeochemistry that occur today could be amplified in the future as sea level rises, water temperature increases, pH decreases, storm events increase in intensity, and rainfall is increasingly delivered in sporadic but high intensity events interspersed with dry periods. Knowing how the region reacts during high flow periods is essential to our understanding of what will happen if those high flow periods become more frequent and/or prolonged. For example, in the plume region alone, I showed that high intensity freshwater flow events could result in large discharges of nutrients, and particulate matter, but not necessarily high productivity. However, it is possible that if a drought situation were to occur following a high discharge event, those nutrients could be made available for productivity in the vicinity of the plume or further downstream, moving the effects of the Chesapeake Bay plume further into the coastal ocean.

FUTURE DIRECTIONS

This study was limited to the water column and there are significant sediment/water interactions, atmosphere/surface water interactions, and small-scale physical processes occurring that were not addressed in this study.

Based on results from this study, future research might be focused on the following questions:

1. What will be the overall N budget balance given current and projected scenarios? Will oversaturation of N in sediments occur, thus releasing

N into the water column? Or, will primary productivity increase organic rain to the sediments thereby stimulating denitrification?

2. Can the MAB be maintained as a C sink if N inputs continue to escalate; can denitrirfication keep up? Or, could the MAB become more of a C sink if primary productivity increases due to eutrophication and denitrification rates are maintained?

It is an unfortunate reality that everything cannot be sampled everywhere, all the time. Based on our data limitations, it is still important to ascertain as best we can a range of plausible scenarios so that we can understand all aligned processes and project into the future. Satellite remote sensing efforts require ground-truthing and it is clear that the relationships between primary productivity and remotely sensed parameters are not always related in a predictable fashion. The body of research presented in this dissertation substantially advances our current understanding of N and C cycling in the MAB and 3 hydrographic provinces therein; areas heavily impacted by climate change, global warming, and human interactions.

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Appendix Table A.1. 2005 – 2007 nitrogenous nutrient concentrations for stations in and around the plume. Units are µmol N L^{-1}. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available, b.l.d.= below the limit of detection (NH_4^+: 0.05; NO_2^-: 0.02; NO_3^-: 0.02; Urea: 0.05; DFAA: 0.03).

									BM								
Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea	+/-	DFAA	+/-	DON	+/-	DIN	+/-
03/30/05	2	36.97	-76.02	0.76	0.02	0.15	0.00	0.24	0.04	0.44	0.01	0.16	0.02	13.28	0.05	1.15	0.05
03/30/05	4.4	36.97	-76.02	0.86	0.04	0.17	0.03	0.24	0.08	0.31	0.00	0.23	0.00	15.30	0.09	1.27	0.09
05/27/05	0	36.97	-76.02	0.77	0.02	0.04	0.00	2.14	0.00	0.39	0.02	0.20	0.02	17.50	1.40	2.94	0.02
05/27/05	9	36.97	-76.02	1.39	0.03	0.25	0.02	0.14	0.03	0.09	0.01	0.14	0.01	6.94	0.17	1.78	0.04
06/21/05	0	36.97	-76.02	0.60	0.10	0.06	0.01	b.l.d.	b.l.d.	0.26	0.02	0.11	0.00	9.60	0.45	0.67	0.10
06/21/05	7	36.97	-76.02	0.67	0.03	0.06	0.03	0.05	0.03	0.10	0.00	0.17	0.01	6.38	0.27	0.79	0.06
07/27/05	2	36.97	-76.02	1.08	0.01	0.17	0.03	0.11	0.06	0.05	0.00	0.20	0.02	21.53	1.24	1.36	0.07
07/27/05	5	36.97	-76.02	0.84	0.02	0.19	0.03	0.24	0.10	0.05	0.02	0.17	0.02	21.97	3.34	1.27	0.11
11/03/05	0	36.97	-76.02	1.08	0.03	1.45	0.04	1.52	0.05	0.11	0.01	0.36	0.03	17.80	2.03	4.04	0.07
11/03/05	14	36.97	-76.02	0.83	0.01	0.70	0.01	1.91	0.02	0.34	0.01	0.22	0.06	23.28	5.85	3.45	0.03
04/20/06	0	36.91	-75.88	0.44	0.02	0.03	0.01	0.22	0.04	0.06	0.01	0.16	0.00	24.72	0.05	0.68	0.05
04/20/06	10	36.91	-75.88	0.50	0.12	0.08	0.01	0.20	0.05	0.06	0.00	0.14	0.03	18.95	0.27	0.78	0.13
05/08/06	2	36.97	-76.02	0.43	0.06	0.12	0.00	0.09	0.00	0.05	0.01	0.21	0.04	27.07	0.30	0.64	0.06
05/08/06	17	36.97	-76.02	0.40	0.04	0.12	0.12	0.08	0.12	0.05	0.00	0.16	0.01	9.10	0.40	0.60	0.17
07/02/06	2	36.97	-76.02	0.38	0.02	0.15	0.00	0.12	0.00	b.l.d.	b.l.d.	0.12	0.01	12.77	1.38	0.65	0.02
07/02/06	6	36.97	-76.02	0.32	0.02	0.13	0.00	0.02	0.00	0.05	0.00	0.09	0.00	7.51	1.61	0.46	0.02
08/24/06	2	36.91	-75.92	0.44	0.01	0.03	0.03	0.20	0.03	0.37	0.04	0.18	0.00	7.41	0.39	0.68	0.04
08/24/06	6	36.91	-75.92	0.43	0.02	0.11	0.00	0.13	0.00	0.46	0.04	0.19	0.07	5.89	0.85	0.66	0.02
09/06/06	1	36.97	-76.02	1.01	0.07	1.03	0.21	0.13	0.21	0.42	0.03	0.17	0.02	19.66	0.31	2.18	0.31
09/06/06	15	36.97	-76.02	3.79	0.20	0.49	0.09	0.48	0.12	0.56	0.01	0.28	0.00	14.55	0.25	4.76	0.25
10/31/06	2	36.97	-76.02	1.17	0.44	0.44	0.07	2.58	0.26	0.36	0.02	0.11	0.02	16.07	0.52	4.18	0.51
10/31/06	6	36.97	-76.02	1.70	0.33	0.33	0.06	0.99	0.06	0.32	0.09	0.16	0.03	19.72	0.37	3.02	0.35
11/28/06	1	36.97	-76.02	0.56	0.09	0.32	0.02	1.97	0.22	0.23	0.02	0.16	0.00	22.44	0.92	2.85	0.24
11/28/06	4	36.97	-76.02	0.68	0.01	0.31	0.03	0.86	0.18	0.23	0.02	0.23	0.02	22.98	1.98	1.86	0.19

Appendix Table A.1. Continued.

Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea	+/-	DFAA	+/-	DON	+/-	DIN	+/-
								BM									
03/19/07	1	36.97	-76.02	0.41	0.04	0.09	0.02	0.15	0.02	0.39	0.07	n.d.	n.d.	21.55	2.75	0.65	0.05
03/19/07	15	36.97	-76.02	0.39	0.04	0.12	0.02	0.15	0.06	0.37	0.12	n.d.	n.d.	26.75	0.27	0.66	0.08
04/23/07	1.5	36.97	-76.02	0.39	0.01	0.14	0.02	0.27	0.04	0.34	0.02	0.46	0.10	12.85	1.91	0.81	0.04
04/23/07	5	36.97	-76.02	0.42	0.02	0.13	0.01	0.18	0.01	0.22	0.03	0.31	0.02	9.71	1.05	0.73	0.02
07/03/07	1.5	36.97	-76.02	0.40	0.04	0.28	0.03	0.04	0.08	0.43	0.04	0.24	0.00	11.99	0.83	0.72	0.09
07/03/07	15	36.97	-76.02	1.05	0.03	0.25	0.00	0.11	0.00	0.39	0.03	0.41	0.00	9.79	0.77	1.42	0.03
08/16/07	1.5	36.97	-76.02	0.25	0.03	0.24	0.00	b.l.d.	b.l.d.	0.92	0.06	0.44	0.40	15.69	0.00	0.50	0.00
08/16/07	12	36.97	-76.02	0.53	0.09	0.21	0.00	0.16	0.00	0.94	0.05	0.28	0.00	14.13	0.00	0.90	0.00
								PL1									
03/30/05	2	36.90	-75.91	0.84	0.05	0.06	0.00	0.28	0.03	0.36	0.03	0.56	0.05	14.89	0.06	1.18	0.06
03/30/05	15	36.90	-75.91	0.84	0.09	0.06	0.00	0.38	0.05	0.12	0.01	0.70	0.07	13.50	0.10	1.28	0.10
05/27/05	0	36.89	-75.91	0.84	0.01	0.09	0.01	2.44	0.01	0.27	0.02	0.18	0.01	9.33	0.70	3.37	0.02
05/27/05	7	36.89	-75.91	1.22	0.01	0.21	0.03	0.16	0.07	0.27	0.02	0.13	0.03	3.93	0.22	1.59	0.08
06/21/05	0	36.89	-75.91	0.71	0.02	0.09	0.01	0.02	0.02	0.19	0.02	0.37	0.12	7.68	0.26	0.81	0.03
06/21/05	8	36.89	-75.91	0.65	0.01	0.05	0.01	0.22	0.02	0.06	0.01	0.30	0.07	4.21	0.06	0.91	0.02
07/27/05	2	36.90	-75.91	0.82	0.01	0.10	0.01	0.58	0.01	0.04	0.04	0.24	0.04	19.90	0.02	1.50	0.02
07/27/05	8	36.90	-75.91	0.78	0.03	0.16	0.00	0.29	0.00	0.05	0.00	0.16	0.04	15.40	3.64	1.22	0.03
11/03/05	0	36.90	-75.91	0.82	0.01	1.86	0.07	1.90	0.07	0.06	0.01	0.28	0.03	24.38	6.04	4.57	0.11
11/03/05	3	36.90	-75.91	0.78	0.03	1.75	0.09	1.82	0.09	b.l.d.	b.l.d.	0.20	0.01	17.11	1.84	4.34	0.14
04/20/06	1	36.91	-75.80	0.49	0.01	0.10	0.03	0.22	0.03	0.03	0.00	0.18	0.06	25.28	0.10	0.80	0.04
04/20/06	13	36.91	-75.80	0.52	0.04	0.16	0.01	0.12	0.01	b.l.d.	b.l.d.	0.15	0.03	21.27	0.55	0.79	0.05
05/08/06	1.5	36.90	-75.91	0.35	0.04	0.14	0.00	0.00	0.01	0.08	0.01	0.24	0.00	12.89	1.88	0.49	0.04
05/08/06	12	36.90	-75.91	0.34	0.03	0.12	0.13	0.01	0.13	0.13	0.00	0.41	0.23	21.09	0.19	0.47	0.19

Appendix Table A.1. Continued.

Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea	+/-	DFAA	+/-	DON	+/-	DIN	+/-
									PL1								
07/02/06	2	36.90	-75.91	0.36	0.03	0.16	0.00	0.08	0.00	0.15	0.01	0.17	0.10	10.21	1.47	0.60	0.03
07/02/06	5	36.90	-75.91	0.35	0.02	0.12	0.02	0.08	0.00	0.12	0.00	0.12	0.03	5.97	1.55	0.55	0.03
08/24/06	0	36.89	-75.73	0.49	0.05	0.16	0.01	0.07	0.01	0.39	0.05	0.19	0.08	9.27	0.66	0.73	0.05
08/24/06	2	36.89	-75.73	0.49	0.02	0.09	0.02	0.09	0.07	0.52	0.07	0.28	0.01	6.78	0.34	0.66	0.07
09/06/06	1.3	36.90	-75.91	0.66	0.04	0.85	0.04	0.12	0.08	0.40	0.05	0.17	0.04	16.55	0.10	1.63	0.10
09/06/06	16	36.90	-75.91	3.86	0.33	0.36	0.10	0.41	0.10	0.32	0.02	0.25	0.01	13.35	0.36	4.64	0.36
10/31/06	2	36.90	-75.91	0.86	0.49	0.49	0.04	1.56	0.49	0.51	0.00	0.22	0.07	17.05	0.72	2.91	0.70
10/31/06	6	36.90	-75.91	1.41	0.26	0.26	0.03	0.95	0.03	0.45	0.13	0.13	0.00	14.73	0.34	2.62	0.26
11/28/06	1	36.90	-75.91	0.96	0.07	0.42	0.02	6.17	0.37	0.10	0.02	0.22	0.03	17.95	1.08	7.55	0.37
11/28/06	3.1	36.90	-75.91	2.18	0.06	0.35	0.04	3.77	0.53	0.19	0.02	0.27	0.04	13.49	1.27	6.31	0.54
03/19/07	1.2	36.92	-76.01	0.37	0.04	0.15	0.02	0.07	0.06	0.37	0.07	n.d.	n.d.	28.33	1.43	0.58	0.08
03/19/07	6	36.92	-76.01	0.35	0.02	0.11	0.02	0.04	0.06	0.15	0.03	n.d.	n.d.	24.85	1.45	0.50	0.07
04/23/07	1	36.92	-76.01	0.67	0.08	0.04	0.00	0.33	0.03	0.09	0.01	0.19	0.04	8.76	0.73	1.04	0.08
04/23/07	4.5	36.92	-76.01	0.60	0.04	0.08	0.00	0.27	0.02	0.15	0.01	0.17	0.07	6.72	0.10	0.96	0.04
07/03/07	1.5	36.92	-76.01	0.19	0.03	0.13	0.02	0.19	0.07	0.38	0.04	0.13	0.00	8.72	0.12	0.51	0.08
07/03/07	8	36.92	-76.01	0.44	0.03	0.11	0.04	0.02	0.00	0.42	0.02	0.19	0.00	10.65	0.00	0.56	0.00
08/16/07	1.5	36.92	-76.01	0.25	0.06	0.17	0.01	0.10	0.06	0.82	0.10	0.08	0.00	12.69	0.83	0.52	0.09
08/16/07	4	36.92	-76.01	0.42	0.05	0.12	0.00	0.04	0.06	0.58	0.02	0.04	0.00	11.32	0.39	0.57	0.08
									PL2								
03/30/05	2	36.80	-75.86	0.99	0.33	0.06	0.03	0.28	0.03	0.12	0.07	0.28	0.03	14.25	0.33	1.32	0.33
03/30/05	13	36.80	-75.86	1.06	0.02	0.08	0.01	0.25	0.07	0.20	0.00	0.33	0.02	10.82	0.07	1.39	0.07
05/27/05	0	36.80	-75.86	0.78	0.04	0.07	0.02	1.43	0.02	0.18	0.01	0.22	0.03	18.83	0.00	2.27	0.05
05/27/05	8	36.80	-75.86	0.82	0.01	0.07	0.01	0.01	0.01	0.32	0.02	0.29	0.02	1.57	0.17	0.90	0.01

Appendix Table A.1. Continued.

				PL2													
Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea	+/-	DFAA	+/-	DON	+/-	DIN	+/-
06/21/05	0	36.80	-75.86	0.68	0.01	0.08	0.01	0.00	0.01	0.07	0.01	0.32	0.00	6.34	0.05	0.75	0.02
06/21/05	15	36.80	-75.86	0.85	0.15	0.05	0.00	0.06	0.04	0.12	0.01	0.72	0.03	5.35	0.00	0.96	0.16
07/27/05	2	36.80	-75.86	0.81	0.02	0.02	0.01	0.43	0.05	0.07	0.01	0.22	0.00	22.98	3.01	1.25	0.05
07/27/05	16	36.80	-75.86	0.85	0.01	0.07	0.01	0.35	0.03	0.05	0.02	0.13	0.01	12.83	5.19	1.27	0.04
11/03/05	0	36.80	-75.86	0.84	0.07	1.03	0.04	0.38	0.05	0.15	0.01	0.41	0.01	16.14	3.44	2.26	0.09
11/03/05	5	36.80	-75.86	0.85	0.01	0.11	0.01	0.02	0.03	0.21	0.02	0.21	0.00	22.07	2.41	0.98	0.03
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.80	-75.86	0.36	0.03	0.12	0.02	0.00	0.02	0.05	0.00	0.24	0.01	14.59	1.84	0.49	0.04
05/08/06	16	36.80	-75.86	0.41	0.02	0.11	0.01	0.02	0.01	0.14	0.01	0.21	0.04	16.37	1.96	0.53	0.02
07/02/06	2	36.80	-75.86	0.34	0.03	0.12	0.01	0.05	0.00	0.12	0.02	0.26	0.04	7.69	0.24	0.51	0.03
07/02/06	6	36.80	-75.86	0.27	0.01	0.15	0.01	0.04	0.00	0.08	0.00	0.23	0.01	5.87	0.98	0.46	0.01
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	1	36.80	-75.86	0.64	0.06	b.l.d.	b.l.d.	0.12	0.01	0.16	0.02	0.24	0.03	19.51	0.06	0.77	0.06
09/06/06	15	36.80	-75.86	4.71	0.13	0.70	0.03	0.66	0.08	0.29	0.03	0.27	0.07	14.86	0.16	6.07	0.16
10/31/06	2	36.80	-75.86	0.45	0.48	0.48	0.06	0.48	0.27	0.36	0.04	0.15	0.00	13.57	0.76	1.42	0.55
10/31/06	5	36.80	-75.86	0.67	0.36	0.36	0.09	0.33	0.11	0.66	0.04	0.12	0.10	24.90	0.40	1.36	0.39
11/28/06	1	36.80	-75.86	0.75	0.04	0.30	0.00	3.43	0.65	0.19	0.01	0.27	0.05	17.53	0.76	4.48	0.65
11/28/06	3.3	36.80	-75.86	1.47	0.06	0.35	0.03	2.99	0.27	0.18	0.03	0.19	0.05	7.02	0.34	4.81	0.28
03/19/07	1	36.80	-75.86	0.33	0.02	0.17	0.01	0.01	0.07	0.29	0.00	n.d.	n.d.	25.39	1.14	0.51	0.07
03/19/07	16	36.80	-75.86	0.32	0.03	0.02	0.00	0.10	0.00	0.05	0.01	n.d.	n.d.	29.87	2.44	0.44	0.03
04/23/07	1.5	36.80	-75.86	1.20	0.08	0.17	0.01	0.18	0.06	0.28	0.02	0.19	0.05	13.99	5.77	1.54	0.10
04/23/07	6	36.80	-75.86	0.69	0.00	0.02	0.00	0.27	0.03	0.10	0.00	0.20	0.05	15.90	5.70	0.99	0.03

Appendix Table A.1. Continued.

Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea	+/-	DFAA	+/-	DON	+/-	DIN	+/-
									PL2								
07/03/07	1.5	36.80	-75.86	0.26	0.04	0.15	0.00	0.03	0.07	0.31	0.03	0.25	0.14	11.04	1.74	0.44	0.08
07/03/07	9.2	36.80	-75.86	n.d.	n.d.	0.18	0.01	0.18	0.01	0.55	0.07	0.96	0.22	9.48	0.19	0.36	0.01
08/16/07	1.5	36.80	-75.86	0.22	0.06	0.09	0.01	0.03	0.01	0.47	0.09	0.45	0.00	11.00	0.37	0.35	0.07
08/16/07	8	36.80	-75.86	0.22	0.09	0.07	0.01	0.05	0.01	0.27	0.06	0.25	0.11	9.84	0.87	0.34	0.09
									PL3								
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.68	-75.6	0.72	0.02	0.08	0.02	0.30	0.02	0.08	0.00	0.14	0.00	16.59	2.81	1.10	0.04
07/27/05	7.6	36.68	-75.6	0.64	0.04	0.07	0.01	0.35	0.07	0.10	0.03	0.13	0.01	12.92	2.66	1.06	0.08
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.67	-75.8	0.39	0.03	0.12	0.00	0.00	0.04	0.07	0.01	0.23	0.01	18.05	0.18	0.51	0.05
05/08/06	17	36.67	-75.8	0.31	0.02	0.13	0.02	0.04	0.14	0.14	0.01	0.25	0.04	20.71	0.16	0.48	0.14
07/02/06	2	36.67	-75.8	0.35	0.04	0.12	0.01	0.04	0.00	b.l.d.	b.l.d.	0.16	0.00	8.81	0.26	0.49	0.04
07/02/06	10	36.67	-75.8	0.29	0.01	0.18	0.03	0.04	0.00	0.06	0.01	0.26	0.03	7.01	1.46	0.48	0.03
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix Table A.1. Continued.

Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea	+/-	DFAA	+/-	DON	+/-	DIN	+/-
										PL3							
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/31/06	2	36.68	-75.76	0.21	0.11	0.11	0.01	0.38	0.14	0.40	0.04	0.19	0.04	3.57	0.17	0.70	0.17
10/31/06	5	36.68	-75.76	0.22	0.13	0.13	0.01	0.12	0.01	0.39	0.04	0.31	0.00	13.27	0.91	0.46	0.13
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
										CLT							
03/30/05	4.5	36.91	-75.71	0.76	0.01	0.18	0.01	0.46	0.01	0.38	0.02	0.21	0.08	19.74	0.02	1.40	0.02
03/30/05	19	36.91	-75.71	0.77	0.03	0.18	0.00	0.30	0.06	0.19	0.02	0.39	0.06	12.32	0.06	1.25	0.06
05/27/05	0	36.91	-75.72	0.77	0.01	0.03	0.01	0.19	0.03	b.l.d.	b.l.d.	0.13	0.01	10.59	1.32	0.99	0.04
05/27/05	6	36.91	-75.72	0.96	0.02	0.08	0.01	0.03	0.01	0.18	0.01	0.10	0.01	6.57	0.19	1.07	0.03
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.91	-75.71	0.74	0.02	0.06	0.01	0.25	0.02	0.08	0.00	0.32	0.04	17.59	0.74	1.05	0.03
07/27/05	12	36.91	-75.71	0.75	0.02	0.16	0.01	0.21	0.06	0.08	0.00	0.17	0.02	10.97	2.11	1.12	0.06

Appendix Table A.1. Continued.

									CLT								
Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea	+/-	DFAA	+/-	DON	+/-	DIN	+/-
11/03/05	0	36.91	-75.71	1.02	0.03	0.15	0.01	0.11	0.02	0.42	0.03	0.20	0.01	16.63	1.05	1.28	0.04
11/03/05	7	36.91	-75.71	1.12	0.01	0.12	0.02	0.16	0.02	0.33	0.01	0.22	0.02	14.48	4.59	1.39	0.03
04/20/06	0	36.91	-75.71	0.56	0.03	0.07	0.01	0.26	0.06	0.11	0.01	0.17	0.00	22.83	0.57	0.89	0.07
04/20/06	11	36.91	-75.71	0.55	0.03	0.09	0.03	0.21	0.03	b.l.d.	b.l.d.	0.18	0.10	20.69	0.05	0.84	0.05
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/02/06	2	36.91	-75.71	0.34	0.03	0.11	0.02	0.07	0.00	0.09	0.01	0.10	0.00	10.35	0.81	0.51	0.03
07/02/06	5.5	36.91	-75.71	0.30	0.02	0.17	0.03	0.04	0.00	0.06	0.01	0.29	0.06	8.31	0.99	0.51	0.03
08/24/06	0	36.91	-75.71	0.55	0.02	0.20	0.02	0.10	0.06	0.38	0.25	0.18	0.02	3.72	1.88	0.84	0.06
08/24/06	0	36.91	-75.71	0.61	0.02	0.13	0.09	0.18	0.20	0.24	0.01	0.15	0.03	1.23	0.47	0.92	0.12
09/06/06	1	36.91	-75.71	0.61	0.00	0.01	0.00	0.31	0.09	0.11	0.05	0.16	0.00	10.78	0.09	0.93	0.09
09/06/06	7	36.91	-75.71	1.12	0.06	0.05	0.02	0.13	0.08	0.38	0.06	0.18	0.02	13.66	0.10	1.29	0.10
10/31/06	2	36.91	-75.71	0.73	0.12	0.12	0.03	0.31	0.08	0.17	0.06	0.17	0.03	4.38	0.14	1.15	0.14
10/31/06	6	36.91	-75.71	0.64	0.09	0.09	0.01	0.36	0.06	0.03	0.01	0.18	0.00	16.14	0.24	1.09	0.11
11/28/06	1	36.91	-75.71	0.63	0.00	0.11	0.01	1.09	0.30	0.07	0.01	0.09	0.03	12.52	0.68	1.83	0.30
11/28/06	5	36.91	-75.71	0.69	0.03	0.13	0.01	1.22	0.12	0.16	0.01	0.22	0.01	12.93	0.42	2.04	0.12
03/19/07	1	36.91	-75.72	0.56	0.06	0.05	0.02	0.10	0.06	0.18	0.01	n.d.	n.d.	11.59	1.82	0.71	0.09
03/19/07	12	36.91	-75.72	0.46	0.06	0.06	0.01	0.06	0.01	0.12	0.01	n.d.	n.d.	21.13	0.77	0.58	0.06
04/23/07	1	36.91	-75.72	0.38	0.03	0.09	0.01	0.06	0.01	0.39	0.05	0.32	0.20	12.06	3.96	0.52	0.03
04/23/07	12	36.91	-75.72	0.36	0.01	b.l.d.	b.l.d.	0.25	0.02	0.23	0.01	0.21	0.01	10.25	0.53	0.63	0.03
07/03/07	1.5	36.91	-75.72	0.18	0.03	0.04	0.01	0.08	0.01	0.36	0.01	0.14	0.00	10.23	0.20	0.30	0.03
07/03/07	11	36.91	-75.72	0.23	0.02	0.09	0.01	0.04	0.01	0.22	0.03	0.22	0.13	8.81	1.16	0.35	0.03
08/16/07	1.5	36.91	-75.72	0.18	0.04	0.10	0.00	0.15	0.00	0.38	0.04	1.04	0.47	11.28	0.75	0.43	0.04
08/16/07	12	36.91	-75.72	0.55	0.09	0.19	0.00	0.22	0.00	1.23	0.09	0.24	0.00	10.12	0.00	0.95	0.00

Appendix Table A.2. 2005 – 2007 PO_4^{3-}, SiO_4^+, DIC, and alkalinity concentrations for stations in and around the plume. Units are in μmol L^{-1} except for alkalinity which is in mmol kg^{-1}. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available, b.l.d.= below the limit of detection (PO_4^{3-}: 0.02; SiO_4^+: 0.05).

						BM					
Date	Depth (m)	Lat.	Lon.	PO_4^{3-}	+/-	SiO_4^+	+/-	DIC	+/-	Alkalinity	+/-
03/30/05	2	36.97	-76.02	0.29	0.02	0.55	0.01	1.56	0.01	1.73	0.03
03/30/05	4.4	36.97	-76.02	0.26	0.03	0.58	0.10	1.72	0.02	1.84	0.01
05/27/05	0	36.97	-76.02	0.46	0.04	1.01	0.78	1.47	0.01	1.45	0.03
05/27/05	9	36.97	-76.02	0.40	0.01	1.78	0.07	1.73	0.01	1.72	0.02
06/21/05	0	36.97	-76.02	0.12	0.01	5.82	0.00	1.56	0.01	1.55	0.01
06/21/05	7	36.97	-76.02	0.04	0.00	5.04	0.00	1.73	0.01	1.70	0.02
07/27/05	2	36.97	-76.02	0.08	0.01	7.02	0.05	1.75	0.00	1.88	0.01
07/27/05	5	36.97	-76.02	0.14	0.00	2.23	0.01	1.81	0.01	1.97	0.01
11/03/05	0	36.97	-76.02	b.l.d.	b.l.d.	13.76	0.07	1.78	0.01	1.94	0.01
11/03/05	14.2	36.97	-76.02	0.55	0.01	9.15	0.09	1.80	0.00	1.96	0.01
04/20/06	0	36.91	-75.88	0.08	0.01	0.91	0.07	1.58	0.03	1.66	0.01
04/20/06	10	36.91	-75.88	0.16	0.01	0.84	0.08	1.84	0.04	2.01	0.02
05/08/06	2	36.97	-76.02	0.04	0.01	0.79	0.01	1.80	0.36	2.10	0.31
05/08/06	17	36.97	-76.02	0.13	0.01	1.03	0.01	2.49	0.15	2.10	0.02
07/02/06	2	36.97	-76.02	0.08	0.01	8.05	0.10	1.86	0.03	1.88	0.01
07/02/06	6	36.97	-76.02	0.21	0.02	4.23	0.23	2.03	0.16	2.03	0.00
08/24/06	2	36.91	-75.92	0.20	0.02	7.40	0.21	2.03	0.04	1.89	0.03
08/24/06	6	36.91	-75.92	0.13	0.00	2.25	0.05	1.96	0.05	2.05	0.03
09/06/06	1	36.97	-76.02	0.30	0.00	18.02	0.47	1.66	0.02	1.87	0.00
09/06/06	14.5	36.97	-76.02	0.65	0.01	13.66	0.21	1.87	0.04	2.07	0.03
10/31/06	2	36.97	-76.02	0.26	0.02	8.40	0.53	1.71	0.03	1.86	0.00
10/31/06	6	36.97	-76.02	0.27	0.01	12.13	0.76	1.85	0.02	1.98	0.01
11/28/06	1	36.97	-76.02	0.04	0.01	14.24	1.30	1.55	0.10	1.64	0.05
11/28/06	4	36.97	-76.02	0.02	0.01	10.85	0.88	1.72	0.01	1.81	0.01

Appendix Table A.2. Continued.

Date	Depth (m)	Lat.	Lon.	PO_4^{3-}	+/-	SiO_4^+	+/-	DIC	+/-	Alkalinity	+/-
						BM					
3/19/2007	1	36.97	-76.02	0.05	0.01	2.01	0.06	n.d.	n.d.	n.d.	n.d.
3/19/2007	15	36.97	-76.02	0.03	0.03	1.79	0.44	n.d.	n.d.	n.d.	n.d.
4/23/2007	1.5	36.97	-76.02	0.46	0.06	0.14	0.02	n.d.	n.d.	n.d.	n.d.
4/23/2007	5	36.97	-76.02	0.28	0.04	0.91	0.02	n.d.	n.d.	n.d.	n.d.
7/3/2007	1.5	36.97	-76.02	0.10	0.01	18.40	0.14	n.d.	n.d.	n.d.	n.d.
7/3/2007	14.5	36.97	-76.02	0.28	0.02	6.27	0.02	n.d.	n.d.	n.d.	n.d.
8/16//07	1.5	36.97	-76.02	0.19	0.02	14.11	0.06	n.d.	n.d.	n.d.	n.d.
8/16//07	12	36.97	-76.02	0.26	0.02	5.78	0.20	n.d.	n.d.	n.d.	n.d.
						PL1					
03/30/05	2	36.90	-75.91	0.38	0.19	0.36	0.22	1.57	0.05	1.57	0.05
03/30/05	15	36.90	-75.91	0.21	0.01	0.75	0.07	1.86	0.03	1.86	0.03
05/27/05	0	36.89	-75.91	0.42	0.01	1.67	0.05	1.48	0.01	1.50	0.03
05/27/05	7	36.89	-75.91	0.39	0.02	1.43	0.19	1.83	0.00	1.78	0.01
06/21/05	0	36.89	-75.91	0.09	0.00	7.19	0.00	1.59	0.00	1.57	0.01
06/21/05	8	36.89	-75.91	0.09	0.00	3.49	0.01	1.91	0.02	1.85	0.00
07/27/05	2	36.90	-75.91	0.16	0.00	3.42	0.00	1.85	0.00	1.99	0.00
07/27/05	8	36.90	-75.91	0.22	0.00	0.16	0.01	1.75	0.04	1.84	0.00
11/03/05	0	36.90	-75.91	0.17	0.02	16.04	0.16	1.79	0.00	1.99	0.00
11/03/05	3	36.90	-75.91	0.22	0.01	15.04	0.14	1.85	0.00	2.05	0.00
04/20/06	1	36.91	-75.80	0.06	0.01	1.35	0.06	1.62	0.09	1.69	0.00
04/20/06	13.4	36.91	-75.80	0.09	0.01	0.28	0.02	1.77	0.05	1.90	0.00
05/08/06	1.5	36.90	-75.91	0.07	0.00	1.13	0.03	2.07	0.05	1.97	0.02
05/08/06	12	36.90	-75.91	0.17	0.00	1.33	0.00	2.02	0.07	2.13	0.01

Appendix Table A.2. Continued.

						PL1					
Date	Depth (m)	Lat.	Lon.	PO_4^{3-}	+/-	SiO_4^{+}	+/-	DIC	+/-	Alkalinity	+/-
07/02/06	2	36.90	-75.91	0.05	0.01	9.25	0.64	1.75	0.01	1.82	0.01
07/02/06	5	36.90	-75.91	0.11	0.00	1.43	0.11	2.07	0.14	2.11	0.00
08/24/06	0	36.89	-75.73	0.18	0.01	6.05	0.04	1.60	0.10	1.89	0.01
08/24/06	2	36.89	-75.73	0.11	0.01	3.35	0.14	1.67	0.16	1.95	0.01
09/06/06	1.3	36.90	-75.91	0.31	0.01	16.88	0.11	1.50	0.04	1.90	0.00
09/06/06	16.2	36.90	-75.91	0.65	0.03	9.84	0.72	1.90	0.03	2.04	0.00
10/31/06	2	36.90	-75.91	0.21	0.02	7.08	0.23	1.70	0.02	1.88	0.02
10/31/06	6	36.90	-75.91	0.25	0.04	15.04	1.03	1.77	0.03	2.00	0.01
11/28/06	1	36.90	-75.91	0.17	0.01	23.20	0.13	1.57	0.02	1.66	0.01
11/28/06	3.1	36.90	-75.91	0.17	0.02	14.75	0.78	1.69	0.12	1.89	0.10
3/19/2007	1.2	36.92	-76.01	0.02	0.01	1.66	0.19	n.d.	n.d.	n.d.	n.d.
3/19/2007	6	36.92	-76.01	b.l.d.	b.l.d.	1.09	0.04	n.d.	n.d.	n.d.	n.d.
4/23/2007	1	36.92	-76.01	0.44	0.02	0.94	0.08	n.d.	n.d.	n.d.	n.d.
4/23/2007	4.5	36.92	-76.01	0.37	0.05	1.70	0.22	n.d.	n.d.	n.d.	n.d.
7/3/2007	1.5	36.92	-76.01	0.16	0.01	14.38	0.23	n.d.	n.d.	n.d.	n.d.
7/3/2007	8	36.92	-76.01	0.14	0.01	3.22	1.10	n.d.	n.d.	n.d.	n.d.
8/16//07	1.5	36.92	-76.01	0.19	0.01	9.10	0.14	n.d.	n.d.	n.d.	n.d.
8/16//07	4	36.92	-76.01	0.15	0.02	5.41	0.12	n.d.	n.d.	n.d.	n.d.
						PL2					
03/30/05	2	36.80	-75.86	0.31	0.02	0.90	0.09	1.62	0.00	1.62	0.00
03/30/05	13	36.80	-75.86	0.22	0.01	0.23	0.14	1.96	0.02	1.96	0.02
05/27/05	0	36.80	-75.86	0.42	0.01	1.48	0.14	1.55	0.01	1.58	0.01
05/27/05	8	36.80	-75.86	0.35	0.03	1.53	0.05	1.86	0.02	1.80	0.09

Appendix Table A.2. Continued.

						PL2					
Date	Depth (m)	Lat.	Lon.	PO_4^{3-}	+/-	SiO_4^+	+/-	DIC (μmol L^{-1})	+/-	Alkalinity	+/-
06/21/05	0	36.80	-75.86	0.06	0.00	6.20	0.00	1.69	0.00	1.67	0.00
06/21/05	14.8	36.80	-75.86	0.09	0.00	2.99	0.01	1.94	0.02	1.87	0.00
07/27/05	2	36.80	-75.86	0.06	0.00	8.68	0.00	2.02	0.01	2.07	0.01
07/27/05	15.6	36.80	-75.86	0.50	0.01	0.72	0.01	1.73	0.01	1.93	0.00
11/03/05	0	36.80	-75.86	0.19	0.00	12.46	0.02	1.93	0.01	2.14	0.00
11/03/05	5	36.80	-75.86	0.18	0.00	7.07	0.04	1.92	0.00	2.14	0.00
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.80	-75.86	0.05	0.01	1.03	0.06	2.33	0.03	1.98	0.02
05/08/06	16	36.80	-75.86	0.17	0.00	1.57	0.00	1.98	0.27	2.10	0.03
07/02/06	2	36.80	-75.86	0.05	0.01	10.35	0.22	1.80	0.05	1.85	0.01
07/02/06	6	36.80	-75.86	0.07	0.00	1.23	0.04	2.01	0.06	2.14	0.00
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	1	36.80	-75.86	0.17	0.01	13.92	0.04	1.73	0.03	2.07	0.03
09/06/06	15.2	36.80	-75.86	0.83	0.05	21.59	0.60	1.93	0.07	2.10	0.02
10/31/06	2	36.80	-75.86	0.19	0.02	6.38	0.23	1.86	0.07	1.98	0.05
10/31/06	5	36.80	-75.86	0.22	0.01	5.06	0.23	1.88	0.06	2.06	0.00
11/28/06	1	36.80	-75.86	0.14	0.06	17.71	0.80	1.82	0.05	2.06	0.01
11/28/06	3.3	36.80	-75.86	0.10	0.00	13.27	1.47	1.87	0.01	2.07	0.00
3/19/2007	1	36.80	-75.86	b.l.d.	b.l.d.	0.69	0.00	n.d.	n.d.	n.d.	n.d.
3/19/2007	15.5	36.80	-75.86	b.l.d.	b.l.d.	0.40	0.02	n.d.	n.d.	n.d.	n.d.
4/23/2007	1.5	36.80	-75.86	0.21	0.03	0.66	0.04	n.d.	n.d.	n.d.	n.d.
4/23/2007	6	36.80	-75.86	0.29	0.04	1.24	0.06	n.d.	n.d.	n.d.	n.d.

Appendix Table A.2. Continued.

Date	Depth (m)	Lat.	Lon.	PO_4^{3-}	+/-	SiO_4^+	+/-	DIC	+/-	Alkalinity	+/-
						PL2					
7/3/2007	1.5	36.80	-75.86	0.07	0.01	12.90	2.00	n.d.	n.d.	n.d.	n.d.
7/3/2007	9.2	36.80	-75.86	0.15	0.01	2.35	0.19	n.d.	n.d.	n.d.	n.d.
8/16//07	1.5	36.80	-75.86	0.05	0.00	0.05	0.00	n.d.	n.d.	n.d.	n.d.
8/16//07	8	36.80	-75.86	0.07	0.00	1.29	0.00	n.d.	n.d.	n.d.	n.d.
						PL3					
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.68	-75.6	b.l.d.	b.l.d.	0.20	0.02	1.73	0.01	1.93	0.00
07/27/05	7.6	36.68	-75.6	0.10	0.00	0.22	0.03	1.91	0.00	2.06	0.00
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.67	-75.8	0.06	0.00	0.99	0.01	1.96	0.01	1.99	0.01
05/08/06	17	36.67	-75.8	0.07	0.00	0.85	0.01	2.15	0.13	2.15	0.01
07/02/06	2	36.67	-75.8	0.03	0.01	8.81	0.87	1.85	0.05	1.93	0.00
07/02/06	10	36.67	-75.8	0.11	0.01	1.32	0.14	1.91	0.04	2.10	0.10
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix Table A.2. Continued.

						PL3					
Date	Depth (m)	Lat.	Lon.	PO_4^{3-}	+/-	SiO_4^+	+/-	DIC	+/-	Alkalinity	+/-
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/31/06	2	36.68	-75.76	0.15	0.02	3.70	0.45	1.83	0.01	2.07	0.01
10/31/06	5	36.68	-75.76	0.15	0.02	3.12	0.15	1.84	0.00	2.09	0.01
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/19/2007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/19/2007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4/23/2007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4/23/2007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
7/3/2007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
7/3/2007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
8/16//07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
8/16//07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
						CLT					
03/30/05	4.5	36.91	-75.71	0.38	0.02	0.54	0.01	1.86	0.07	2.19	0.00
03/30/05	18.5	36.91	-75.71	0.32	0.02	0.79	0.09	1.91	0.02	2.18	0.01
05/27/05	0	36.91	-75.72	0.37	0.01	1.60	0.01	1.82	0.00	1.76	0.00
05/27/05	6	36.91	-75.72	0.47	0.00	1.41	0.01	1.90	0.01	1.83	0.03
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.91	-75.71	0.08	0.01	0.39	0.00	1.82	0.01	2.00	0.00
07/27/05	12.3	36.91	-75.71	0.32	0.00	0.68	0.01	1.98	0.01	2.12	0.03

Appendix Table A.2. Continued

Date	Depth (m)	Lat.	Lon.	PO_4^{3-} (μmol L^{-1})	+/-	CLT SiO_4^{+} (μmol L^{-1})	+/-	DIC (μmol L^{-1})	+/-	Alkalinity	+/-
11/03/05	0	36.91	-75.71	0.28	0.01	3.43	0.01	1.68	0.12	1.96	0.05
11/03/05	7	36.91	-75.71	0.28	0.00	3.25	0.03	1.91	0.06	2.06	0.01
04/20/06	0	36.91	-75.71	b.l.d.	b.l.d.	1.17	0.02	1.55	0.05	1.73	0.01
04/20/06	10.5	36.91	-75.71	0.04	0.01	0.32	0.04	1.75	0.01	1.88	0.07
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/02/06	2	36.91	-75.71	0.06	0.01	7.16	0.84	1.84	0.07	1.94	0.01
07/02/06	5.5	36.91	-75.71	0.05	0.01	4.93	0.37	1.95	0.13	1.97	0.01
08/24/06	0	36.91	-75.71	0.10	0.01	0.25	0.11	1.91	0.10	2.11	0.04
08/24/06	0	36.91	-75.71	0.33	0.09	1.53	0.65	2.10	0.17	2.15	0.03
09/06/06	1	36.91	-75.71	0.22	0.02	5.10	0.36	1.84	0.01	1.79	0.06
09/06/06	7	36.91	-75.71	0.37	0.04	4.70	0.01	1.90	0.14	2.02	0.00
10/31/06	2	36.91	-75.71	0.23	0.02	4.09	0.00	1.89	0.01	2.08	0.00
10/31/06	6	36.91	-75.71	0.22	0.02	3.74	0.08	1.86	0.07	2.01	0.08
11/28/06	1	36.91	-75.71	0.15	0.03	1.54	0.06	1.64	0.09	1.63	0.00
11/28/06	5	36.91	-75.71	0.19	0.02	1.11	0.01	1.61	0.17	1.79	0.11
3/19/2007	1	36.91	-75.72	0.05	0.03	b.l.d.	b.l.d.	n.d.	n.d.	n.d.	n.d.
3/19/2007	12	36.91	-75.72	0.05	0.01	0.06	0.01	n.d.	n.d.	n.d.	n.d.
4/23/2007	1	36.91	-75.72	0.42	0.06	0.43	0.04	n.d.	n.d.	n.d.	n.d.
4/23/2007	12	36.91	-75.72	0.42	0.02	0.31	0.00	n.d.	n.d.	n.d.	n.d.
7/3/2007	1.5	36.91	-75.72	0.06	0.01	1.59	0.02	n.d.	n.d.	n.d.	n.d.
7/3/2007	10.8	36.91	-75.72	0.04	0.01	1.62	0.03	n.d.	n.d.	n.d.	n.d.
8/16//07	1.5	36.91	-75.72	0.09	0.00	0.20	0.08	n.d.	n.d.	n.d.	n.d.
8/16//07	12	36.91	-75.72	0.30	0.05	2.14	0.02	n.d.	n.d.	n.d.	n.d.

Appendix table A.3. 2005 – 2007 Chl *a*, PN, and PC concentrations for stations in and around the plume. Units are in μg chl L^{-1} for Chl *a*, and μmol L^{-1} for PN and PC. Standard deviations (±) are shown next to average (n=2). n.d.= no data available, b.l.d.= below the limit of detection (Chl *a*: 0.002; PN: 0.25; PC: 2.6).

				BM					
Date	Depth (m)	Lat.	Lon.	Chl *a*	+/-	PN	+/-	PC	+/-
03/30/05	2	36.97	-76.02	5.54	0.02	4.62	0.55	30.74	3.00
03/30/05	4.4	36.97	-76.02	4.68	0.85	5.58	1.83	34.77	10.12
05/27/05	0	36.97	-76.02	7.58	0.04	9.61	0.62	57.22	2.76
05/27/05	9	36.97	-76.02	3.87	0.18	5.27	0.20	34.13	0.40
06/21/05	0	36.97	-76.02	2.79	0.11	13.07	1.29	74.95	8.79
06/21/05	7	36.97	-76.02	3.05	0.04	10.39	0.37	57.65	2.70
07/27/05	2	36.97	-76.02	2.23	0.00	4.51	0.11	28.62	0.31
07/27/05	5	36.97	-76.02	1.31	0.04	3.33	0.10	25.05	0.26
11/03/05	0	36.97	-76.02	8.53	1.52	8.52	0.56	61.45	0.97
11/03/05	14.2	36.97	-76.02	8.11	1.93	14.91	0.18	105.02	9.41
04/20/06	0	36.91	-75.88	1.03	0.10	4.94	0.16	35.75	0.31
04/20/06	10	36.91	-75.88	1.27	0.25	5.36	0.80	40.12	3.56
05/08/06	2	36.97	-76.02	3.07	0.10	7.15	0.25	56.79	3.10
05/08/06	17	36.97	-76.02	2.87	0.04	4.88	0.50	46.13	2.67
07/02/06	2	36.97	-76.02	3.54	0.07	8.82	0.43	51.16	3.22
07/02/06	6	36.97	-76.02	4.20	0.03	7.32	0.44	41.36	0.46
08/24/06	2	36.91	-75.92	1.41	0.10	4.59	0.46	33.90	0.87
08/24/06	6	36.91	-75.92	1.28	0.05	3.99	0.91	34.12	7.43
09/06/06	1	36.97	-76.02	5.80	0.07	9.41	0.23	64.84	3.12
09/06/06	14.5	36.97	-76.02	3.61	0.07	8.09	0.21	73.88	4.06
10/31/06	2	36.97	-76.02	3.88	0.71	6.03	0.22	39.19	0.44
10/31/06	6	36.97	-76.02	3.80	0.27	5.06	0.27	35.44	0.11
11/28/06	1	36.97	-76.02	7.12	0.60	7.13	1.49	46.57	7.15
11/28/06	4	36.97	-76.02	5.02	1.61	8.61	0.38	55.07	3.76

Appendix Table A.3. Continued

Date	Depth (m)	Lat.	Lon.	Chl *a*	+/-	PN	+/-	PC	+/-
				BM					
03/19/07	1	36.97	-76.02	8.01	0.55	10.02	0.16	58.71	2.44
03/19/07	15	36.97	-76.02	5.98	0.11	6.98	0.22	41.38	1.22
04/23/07	1.5	36.97	-76.02	7.70	0.00	9.48	0.95	62.34	4.33
04/23/07	5	36.97	-76.02	5.70	0.14	7.85	0.25	50.86	1.90
07/03/07	1.5	36.97	-76.02	5.02	0.34	13.23	0.57	85.50	0.28
07/03/07	14.5	36.97	-76.02	1.88	0.04	3.70	0.09	29.18	2.74
08/16/07	1.5	36.97	-76.02	2.99	0.03	6.38	0.61	42.39	3.85
08/16/07	12	36.97	-76.02	4.42	0.07	3.60	0.07	27.32	3.65
				PL1					
03/30/05	2	36.90	-75.91	12.05	0.42	12.73	0.38	85.21	10.21
03/30/05	15	36.90	-75.91	3.09	0.17	3.96	0.69	28.52	3.84
05/27/05	0	36.89	-75.91	6.15	0.00	8.59	0.76	57.58	9.62
05/27/05	7	36.89	-75.91	2.65	0.09	4.05	0.54	26.82	2.73
06/21/05	0	36.89	-75.91	3.52	0.19	11.01	0.60	59.79	3.03
06/21/05	8	36.89	-75.91	2.19	0.03	5.34	0.63	30.29	3.38
07/27/05	2	36.90	-75.91	2.32	0.01	5.38	0.15	38.97	1.66
07/27/05	8	36.90	-75.91	2.31	0.05	5.26	0.16	44.72	2.83
11/03/05	0	36.90	-75.91	8.30	0.78	8.80	0.58	51.77	0.19
11/03/05	3	36.90	-75.91	8.64	0.48	8.52	0.59	48.31	3.54
04/20/06	1	36.91	-75.80	1.13	0.01	4.77	0.07	34.74	1.19
04/20/06	13.4	36.91	-75.80	1.45	0.13	4.52	0.88	32.22	2.56
05/08/06	1.5	36.90	-75.91	2.95	0.03	5.75	0.48	48.63	2.61
05/08/06	12	36.90	-75.91	2.83	0.24	6.89	0.33	58.20	0.37

Appendix Table A.3. Continued.

Date	Depth (m)	Lat.	Lon.	Chl *a*	+/-	PN	+/-	PC	+/-
					PL1				
07/02/06	2	36.90	-75.91	3.98	0.00	9.10	1.27	55.98	3.72
07/02/06	5	36.90	-75.91	3.86	0.12	6.50	0.13	43.04	0.39
08/24/06	0	36.89	-75.73	1.10	0.06	4.30	0.02	31.78	0.00
08/24/06	2	36.89	-75.73	1.24	0.11	3.85	0.15	31.89	2.78
09/06/06	1.3	36.90	-75.91	5.88	0.04	8.64	0.07	61.97	0.94
09/06/06	16.2	36.90	-75.91	1.81	0.07	4.77	0.30	52.88	5.68
10/31/06	2	36.90	-75.91	5.88	0.18	6.74	0.19	44.55	0.72
10/31/06	6	36.90	-75.91	3.28	0.35	4.33	0.27	31.25	0.39
11/28/06	1	36.90	-75.91	8.55	1.27	7.35	0.54	49.01	2.71
11/28/06	3.1	36.90	-75.91	5.06	0.13	5.97	0.12	40.79	0.50
03/19/07	1.2	36.92	-76.01	6.68	0.25	8.95	0.62	50.19	1.22
03/19/07	6	36.92	-76.01	6.45	0.28	8.14	0.23	49.33	1.62
04/23/07	1	36.92	-76.01	4.64	0.49	7.19	1.06	49.23	6.63
04/23/07	4.5	36.92	-76.01	6.53	0.53	8.62	0.54	54.02	2.30
07/03/07	1.5	36.92	-76.01	3.18	0.11	3.05	0.76	21.14	3.40
07/03/07	8	36.92	-76.01	2.21	0.11	9.14	0.47	60.11	3.04
08/16/07	1.5	36.92	-76.01	4.43	0.03	5.32	0.12	34.98	1.49
08/16/07	4	36.92	-76.01	4.48	0.10	4.18	0.19	29.43	0.14
					PL2				
03/30/05	2	36.80	-75.86	9.08	1.10	9.82	1.31	73.65	20.37
03/30/05	13	36.80	-75.86	3.31	0.00	4.56	0.06	32.40	2.27
05/27/05	0	36.80	-75.86	4.06	0.07	5.58	0.26	35.04	1.89
05/27/05	8	36.80	-75.86	2.85	0.00	3.95	0.10	25.89	2.23

Appendix Table A.3. Continued

				PL2					
Date	Depth (m)	Lat.	Lon.	Chl *a*	+/-	PN	+/-	PC	+/-
06/21/05	0	36.80	-75.86	2.09	0.01	8.51	0.60	49.94	3.43
06/21/05	14.8	36.80	-75.86	2.62	0.03	5.85	0.52	38.79	1.23
07/27/05	2	36.80	-75.86	1.29	0.35	5.31	0.00	40.88	0.39
07/27/05	15.6	36.80	-75.86	6.55	0.28	11.05	0.54	73.33	3.58
11/03/05	0	36.80	-75.86	7.10	0.28	8.43	0.38	56.54	1.17
11/03/05	5	36.80	-75.86	7.20	0.64	7.01	0.21	53.01	4.67
04/20/06	0	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	0	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.80	-75.86	2.05	0.00	5.11	0.18	46.17	0.74
05/08/06	16	36.80	-75.86	1.84	0.21	4.10	0.00	42.26	0.06
07/02/06	2	36.80	-75.86	2.78	0.34	9.76	0.32	59.45	2.15
07/02/06	6	36.80	-75.86	3.18	0.10	5.65	0.90	44.83	3.63
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	1	36.80	-75.86	7.30	0.14	10.24	0.09	66.16	1.25
09/06/06	15.2	36.80	-75.86	4.07	0.26	8.62	0.32	81.39	10.92
10/31/06	2	36.80	-75.86	3.99	0.69	5.22	0.32	35.48	0.06
10/31/06	5	36.80	-75.86	3.80	0.29	4.07	0.00	28.71	2.65
11/28/06	1	36.80	-75.86	6.93	0.11	7.87	0.23	52.02	0.44
11/28/06	3.3	36.80	-75.86	4.62	0.18	5.49	0.13	36.10	1.05
03/19/07	1	36.80	-75.86	5.43	0.25	6.85	0.11	45.98	1.49
03/19/07	15.5	36.80	-75.86	9.20	0.28	11.38	0.27	93.55	1.35
04/23/07	1.5	36.80	-75.86	2.67	0.30	6.29	0.01	44.73	0.81
04/23/07	6	36.80	-75.86	6.85	0.49	7.91	0.21	53.92	2.98

Appendix Table A.3. Continued

Date	Depth (m)	Lat.	Lon.	Chl *a*	+/-	PN	+/-	PC	+/-
				PL2					
07/03/07	1.5	36.80	-75.86	2.25	0.03	8.34	0.11	60.73	3.96
07/03/07	9.2	36.80	-75.86	1.42	0.10	3.66	0.02	41.79	18.87
08/16/07	1.5	36.80	-75.86	0.65	0.02	1.54	0.20	12.66	0.72
08/16/07	8	36.80	-75.86	0.75	0.02	1.99	0.09	14.60	1.06
				PL3					
03/30/05	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/30/05	13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.68	-75.6	0.85	0.05	2.78	0.03	35.48	0.62
07/27/05	7.6	36.68	-75.6	1.04	0.02	4.02	0.43	42.65	0.49
11/03/05	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/03/05	13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.67	-75.8	1.56	0.04	4.84	0.10	46.79	0.87
05/08/06	17	36.67	-75.8	1.67	0.05	4.17	0.10	43.58	0.43
07/02/06	2	36.67	-75.8	1.88	0.08	7.86	0.12	52.05	0.61
07/02/06	10	36.67	-75.8	1.93	0.18	3.46	0.02	32.66	1.14
08/24/06	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix Table A.3. Continued.

					PL3				
Date	Depth (m)	Lat.	Lon.	Chl *a*	+/-	PN	+/-	PC	+/-
09/06/06	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/31/06	2	36.68	-75.76	3.24	0.36	4.57	0.19	36.22	0.33
10/31/06	5	36.68	-75.76	4.79	0.01	4.61	0.51	35.44	2.65
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
					CLT				
03/30/05	4.5	36.91	-75.71	0.78	0.08	2.77	0.02	17.89	0.37
03/30/05	18.5	36.91	-75.71	0.76	0.07	2.58	0.38	16.01	0.50
05/27/05	0	36.91	-75.72	1.69	0.10	3.35	0.20	23.17	2.03
05/27/05	6	36.91	-75.72	1.47	0.23	3.03	0.54	21.80	2.75
06/21/05	0	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	0	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.91	-75.71	0.90	0.00	4.21	0.61	40.59	3.41
07/27/05	12.3	36.91	-75.71	1.88	0.01	4.66	0.46	33.73	2.39

Appendix Table A.3. Continued.

				CLT					
Date	Depth (m)	Lat.	Lon.	Chl *a*	+/-	PN	+/-	PC	+/-
11/03/05	0	36.91	-75.71	2.19	0.37	5.05	2.94	37.82	15.70
11/03/05	7	36.91	-75.71	2.69	0.16	3.59	0.08	29.54	0.03
04/20/06	0	36.91	-75.71	0.57	0.01	3.54	0.04	28.51	0.62
04/20/06	10.5	36.91	-75.71	1.63	0.25	3.73	0.01	37.52	2.50
05/08/06	0	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	0	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/02/06	2	36.91	-75.71	2.13	0.19	8.97	0.05	58.21	2.06
07/02/06	5.5	36.91	-75.71	2.05	0.01	7.98	0.25	52.17	1.05
08/24/06	2	36.91	-75.71	0.20	0.05	1.26	0.38	13.76	1.56
08/24/06	12	36.91	-75.71	0.60	0.22	1.64	0.28	15.62	1.45
09/06/06	1	36.91	-75.71	2.02	0.02	5.44	0.00	46.57	0.00
09/06/06	7	36.91	-75.71	2.50	0.11	n.d.	n.d.	n.d.	n.d.
10/31/06	2	36.91	-75.71	2.17	0.18	3.80	1.07	23.83	5.31
10/31/06	6	36.91	-75.71	2.49	0.16	3.02	0.07	20.00	0.48
11/28/06	1	36.91	-75.71	3.87	0.14	5.21	0.31	38.64	1.62
11/28/06	5	36.91	-75.71	2.97	0.05	4.14	0.13	30.35	1.47
03/19/07	1	36.91	-75.72	1.04	0.08	3.34	0.26	22.10	3.16
03/19/07	12	36.91	-75.72	1.41	0.17	3.31	0.26	22.67	1.44
04/23/07	1	36.91	-75.72	4.17	0.61	5.94	0.10	40.03	0.72
04/23/07	12	36.91	-75.72	1.26	0.04	3.88	0.37	29.18	2.35
07/03/07	1.5	36.91	-75.72	0.27	0.00	1.90	0.13	14.54	0.89
07/03/07	10.8	36.91	-75.72	0.43	0.00	1.82	0.20	14.25	1.54
08/16/07	1.5	36.91	-75.72	0.83	0.04	1.88	0.03	15.09	0.00
08/16/07	12	36.91	-75.72	0.62	0.01	0.56	0.79	4.68	6.62

Appendix Table A.4. 2005 – 2007 Hourly volumetric, daily volumetric, and Chl *a* normalized daily bicarbonate uptake rates for stations in and around the plume. Units are shown. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available.

				BM					
Date	Depth (m)	Lat.	Lon.	HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
03/30/05	2	36.97	-76.02	0.75	0.04	8.98	0.51	1.62	0.06
03/30/05	4.4	36.97	-76.02	0.35	0.01	4.22	0.10	1.41	0.03
05/27/05	0	36.97	-76.02	1.79	0.62	21.45	7.49	2.83	0.35
05/27/05	9	36.97	-76.02	1.03	0.25	12.34	3.06	2.64	0.31
06/21/05	0	36.97	-76.02	1.63	0.15	19.60	1.77	7.04	0.10
06/21/05	7	36.97	-76.02	0.57	0.11	6.81	1.34	1.76	0.20
07/27/05	2	36.97	-76.02	0.67	0.02	8.10	0.30	3.64	0.04
07/27/05	5	36.97	-76.02	1.41	0.17	16.93	2.03	5.55	0.12
11/03/05	0	36.97	-76.02	3.27	0.18	78.37	4.23	4.60	0.19
11/03/05	14.2	36.97	-76.02	0.55	0.02	13.20	0.47	5.06	0.05
04/20/06	0	36.91	-75.88	0.12	0.13	2.78	3.08	1.35	1.11
04/20/06	10	36.91	-75.88	1.55	0.06	37.23	1.36	2.29	0.24
05/08/06	2	36.97	-76.02	1.12	0.04	13.48	0.44	4.39	0.05
05/08/06	17	36.97	-76.02	0.18	0.00	2.17	0.04	1.70	0.20
07/02/06	2	36.97	-76.02	0.43	0.06	10.36	1.33	1.46	0.13
07/02/06	6	36.97	-76.02	0.97	0.06	23.30	1.56	4.07	0.07
08/24/06	2	36.91	-75.92	0.15	0.04	3.57	1.04	1.27	0.30
08/24/06	6	36.91	-75.92	0.35	0.01	8.30	0.12	0.99	0.02
09/06/06	1	36.97	-76.02	0.71	0.07	17.13	1.60	1.48	0.09
09/06/06	14.5	36.97	-76.02	0.12	0.00	2.86	0.03	1.12	0.04
10/31/06	2	36.97	-76.02	0.37	0.02	8.86	0.43	1.14	0.19
10/31/06	6	36.97	-76.02	0.37	0.06	8.86	1.34	1.23	0.15
11/28/06	1	36.97	-76.02	0.46	0.07	11.03	1.75	0.77	0.18
11/28/06	4	36.97	-76.02	0.29	0.02	6.93	0.51	0.91	0.10

Appendix Table A.4. Continued.

Date	Depth (m)			HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
						BM			
03/19/07	1	36.97	-76.02	0.32	0.06	7.64	1.34	0.48	0.19
03/19/07	15	36.97	-76.02	0.40	0.03	9.55	0.79	0.95	0.33
04/23/07	1.5	36.97	-76.02	0.16	0.00	3.83	0.10	0.32	0.03
04/23/07	5	36.97	-76.02	0.13	0.02	3.20	0.55	0.28	0.17
07/03/07	1.5	36.97	-76.02	0.24	0.03	2.87	0.39	0.37	0.14
07/03/07	n.d.	36.97	-76.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	1.5	36.97	-76.02	0.51	n.d.	6.14	n.d.	1.22	n.d.
08/16/07	n.d.	36.97	-76.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
						PL1			
03/30/05	n.d.	36.90	-75.91	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/30/05	n.d.	36.90	-75.91	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	0	36.89	-75.91	1.98	0.57	23.79	6.85	3.87	0.29
05/27/05	7	36.89	-75.91	0.83	0.28	9.94	3.35	3.75	0.34
06/21/05	0	36.89	-75.91	2.10	0.06	25.15	0.72	7.15	0.06
06/21/05	8	36.89	-75.91	0.78	0.07	9.34	0.89	4.27	0.10
07/27/05	2	36.90	-75.91	1.27	0.16	15.28	1.95	6.60	0.13
07/27/05	8	36.90	-75.91	0.54	0.02	6.52	0.18	2.83	0.04
11/03/05	0	36.90	-75.91	2.32	0.16	55.57	3.80	3.35	0.12
11/03/05	3	36.90	-75.91	1.77	0.38	42.42	9.04	2.46	0.22
04/20/06	1	36.91	-75.80	0.21	0.04	5.02	0.90	2.23	0.18
04/20/06	13.4	36.91	-75.80	0.06	0.07	1.46	1.74	0.50	1.20
05/08/06	1.5	36.90	-75.91	1.23	0.06	14.75	0.71	5.00	0.05
05/08/06	12	36.90	-75.91	0.77	0.02	9.27	0.20	3.27	0.09

Appendix Table A.4. Continued.

Date	Depth (m)	Lat.	Lon.	HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
						PL1			
07/02/06	2	36.90	-75.91	0.38	0.04	9.03	1.06	1.14	0.12
07/02/06	5	36.90	-75.91	0.34	0.00	8.09	0.10	1.05	0.03
08/24/06	0	36.89	-75.73	0.18	0.03	4.29	0.64	1.96	0.16
08/24/06	2	36.89	-75.73	0.06	0.09	1.34	2.12	0.54	1.58
09/06/06	1.3	36.90	-75.91	0.50	0.12	12.10	2.92	1.03	0.24
09/06/06	16.2	36.90	-75.91	0.17	0.04	4.18	1.07	1.15	0.26
10/31/06	2	36.90	-75.91	0.55	0.02	13.12	0.51	1.12	0.05
10/31/06	6	36.90	-75.91	0.33	0.01	7.97	0.31	1.21	0.11
11/28/06	1	36.90	-75.91	0.42	0.00	10.19	0.09	0.60	0.15
11/28/06	3.1	36.90	-75.91	0.22	0.01	5.22	0.24	0.52	0.05
03/19/07	1.2	36.92	-76.01	0.25	0.01	5.90	0.32	0.44	0.07
03/19/07	6	36.92	-76.01	0.19	0.00	4.59	0.08	0.36	0.05
04/23/07	1	36.92	-76.01	0.21	n.d.	5.00	n.d.	0.54	n.d.
04/23/07	4.5	36.92	-76.01	0.23	0.06	5.56	1.52	0.43	0.28
07/03/07	1.5	36.92	-76.01	0.15	0.00	2.87	0.39	0.57	0.03
07/03/07	n.d.	36.92	-76.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	1.5	36.92	-76.01	0.30	0.01	6.14	n.d.	0.80	0.02
08/16/07	n.d.	36.92	-76.01	n.d.	n.d.	n.d.			n.d.
						PL2			
03/30/05	2	36.80	-75.86	0.12	0.02	1.50	0.29	0.17	0.23
03/30/05	13	36.80	-75.86	0.04	0.00	0.51	0.01	0.15	0.03
05/27/05	0	36.80	-75.86	0.58	0.52	6.97	6.25	1.72	0.90
05/27/05	8	36.80	-75.86	0.25	0.35	2.99	4.23	1.05	1.41

Appendix Table A.4. Continued.

				PL2					
Date	Depth (m)	Lat.	Lon.	HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
06/21/05	0	36.80	-75.86	1.10	0.04	13.19	0.49	6.31	0.04
06/21/05	14.8	36.80	-75.86	0.77	0.07	9.27	0.80	3.54	0.09
07/27/05	2	36.80	-75.86	0.87	0.03	10.46	0.39	8.14	0.28
07/27/05	15.6	36.80	-75.86	1.21	0.07	14.46	0.80	2.21	0.07
11/03/05	0	36.80	-75.86	2.39	0.43	57.43	10.28	4.04	0.18
11/03/05	5	36.80	-75.86	2.35	0.06	56.43	1.33	3.92	0.09
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.80	-75.86	0.10	0.01	1.19	0.08	0.58	0.07
05/08/06	16	36.80	-75.86	0.16	0.02	1.95	0.27	1.06	0.18
07/02/06	2	36.80	-75.86	0.40	0.02	9.49	0.47	1.70	0.13
07/02/06	6	36.80	-75.86	0.22	0.04	5.34	1.05	0.84	0.20
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	1	36.80	-75.86	0.57	0.03	13.59	0.80	0.93	0.06
09/06/06	15.2	36.80	-75.86	0.32	0.07	7.67	1.74	0.94	0.24
10/31/06	2	36.80	-75.86	0.41	0.01	9.92	0.21	1.24	0.17
10/31/06	5	36.80	-75.86	0.36	0.01	8.57	0.26	1.13	0.08
11/28/06	1	36.80	-75.86	0.44	0.04	10.63	0.93	0.77	0.09
11/28/06	3.3	36.80	-75.86	0.19	0.00	4.53	0.08	0.49	0.04
03/19/07	1	36.80	-75.86	0.04	0.00	0.89	0.01	0.08	0.05
03/19/07	15.5	36.80	-75.86	0.10	0.01	2.31	0.13	0.13	0.06
04/23/07	1.5	36.80	-75.86	0.12	0.03	2.99	0.66	0.56	0.25
04/23/07	6	36.80	-75.86	0.24	0.01	5.83	0.26	0.43	0.08

Appendix Table A.4. Continued.

						PL2			
Date	Depth (m)	Lat.	Lon.	HCO_3^- (µmol L^{-1} h^{-1})	+/-	HCO_3^- (µmol L^{-1} d^{-1})	+/-	HCO_3^- (µmol µg chl^{-1} d^{-1})	+/-
07/03/07	1.5	36.80	-75.86	0.27	0.02	2.87	0.39	1.43	0.09
07/03/07	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	1.5	36.80	-75.86	0.03	0.00	6.14	n.d.	0.48	0.15
08/16/07	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
						PL3			
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.68	-75.6	0.49	0.01	5.86	0.15	6.92	0.06
07/27/05	7.6	36.68	-75.6	0.29	0.00	3.43	0.00	3.31	0.02
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.67	-75.8	0.69	0.04	8.32	0.43	5.33	0.06
05/08/06	17	36.67	-75.8	0.68	0.00	8.21	0.01	4.93	0.03
07/02/06	2	36.67	-75.8	0.29	0.01	6.93	0.20	1.85	0.05
07/02/06	10	36.67	-75.8	0.18	0.01	4.21	0.18	1.09	0.10
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix Table A.4. Continued.

Date	Depth (m)	Lat.	Lon.	HCO_3^- (µmol L^{-1} h^{-1})	+/-	HCO_3^- (µmol L^{-1} d^{-1})	+/-	HCO_3^- (µmol µg chl^{-1} d^{-1})	+/-
PL3									
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/31/06	2	36.68	-75.76	0.49	0.01	5.86	0.15	6.92	0.06
10/31/06	5	36.68	-75.76	0.29	0.00	3.43	0.00	3.31	0.02
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CLT									
03/30/05	4.5	36.91	-75.71	0.23	0.03	2.76	0.34	3.55	0.16
03/30/05	18.5	36.91	-75.71	0.21	0.01	2.47	0.12	3.24	0.11
05/27/05	0	36.91	-75.72	0.02	0.01	0.23	0.15	0.14	0.66
05/27/05	6	36.91	-75.72	0.00	0.00	0.03	0.03	0.02	0.91
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.91	-75.71	0.58	0.17	6.95	2.04	7.72	0.29
07/27/05	12.3	36.91	-75.71	0.36	0.03	4.36	0.33	2.31	0.08

Appendix Table. A.4. Continued.

						CLT			
Date	Depth (m)	Lat.	Lon.	HCO_3^- (µmol L^{-1} h^{-1})	+/-	HCO_3^- (µmol L^{-1} d^{-1})	+/-	HCO_3^- (µmol µg chl^{-1} d^{-1})	+/-
11/03/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/03/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	0	36.91	-75.71	0.13	0.00	3.09	0.08	2.71	0.03
04/20/06	10.5	36.91	-75.71	0.10	0.13	2.49	3.18	0.76	1.29
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/02/06	2	36.91	-75.71	0.32	0.02	7.66	0.53	1.80	0.11
07/02/06	5.5	36.91	-75.71	0.24	0.00	5.86	0.03	1.43	0.01
08/24/06	0	36.91	-75.71	0.03	0.00	0.62	0.02	1.53	0.24
08/24/06	0	36.91	-75.71	0.03	0.00	0.77	0.02	0.64	0.37
09/06/06	1	36.91	-75.71	0.09	0.00	2.28	0.08	0.56	0.04
09/06/06	7	36.91	-75.71	0.17	0.04	4.05	1.06	0.81	0.27
10/31/06	2	36.91	-75.71	0.19	0.02	4.58	0.51	1.06	0.14
10/31/06	6	36.91	-75.71	0.27	0.02	6.57	0.40	1.32	0.09
11/28/06	1	36.91	-75.71	0.14	0.01	3.40	0.17	0.44	0.06
11/28/06	5	36.91	-75.71	0.13	0.00	3.01	0.03	0.51	0.02
03/19/07	1	36.91	-75.72	0.14	0.06	3.45	1.39	1.67	0.41
03/19/07	12	36.91	-75.72	0.12	0.06	2.96	1.39	1.05	0.49
04/23/07	1	36.91	-75.72	0.26	0.14	6.25	3.47	0.75	0.57
04/23/07	12	36.91	-75.72	0.06	0.03	1.43	0.75	0.57	0.52
07/03/07	1.5	36.91	-75.72	0.04	0.02	0.93	0.51	1.75	0.55
07/03/07	n.d.	36.91	-75.72	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	1.5	36.91	-75.72	0.08	0.05	2.00	1.30	1.21	0.65
08/16/07	n.d.	36.91	-75.72	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix Table A.5. 2005 – 2007 NH_4^+, NO_2^-, NO_3^-, urea N, and DFAA N volumetric uptake rates for stations in and around the plume. Units are in µmol $L^{-1} h^{-1}$. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available.

							BM						
Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea N	+/-	DFAA N	+/-
03/30/05	2	36.97	-76.02	0.065	0.008	0.006	0.002	0.022	0.014	0.040	0.015	0.043	0.003
03/30/05	4.4	36.97	-76.02	0.091	0.056	0.007	0.002	0.024	0.001	0.026	0.010	0.040	0.009
05/27/05	0	36.97	-76.02	0.116	0.003	0.002	0.000	0.045	0.011	0.045	0.003	0.038	0.001
05/27/05	9	36.97	-76.02	0.066	0.005	0.002	0.000	0.002	0.000	0.007	0.002	0.015	0.001
06/21/05	0	36.97	-76.02	0.246	0.014	0.053	0.007	0.035	0.004	0.179	0.024	0.095	0.011
06/21/05	7	36.97	-76.02	0.188	0.007	0.039	0.004	0.035	0.002	0.074	0.003	0.055	0.002
07/27/05	2	36.97	-76.02	0.353	0.027	0.059	0.001	0.038	0.018	0.056	0.008	0.032	0.001
07/27/05	5	36.97	-76.02	0.215	0.010	0.012	0.000	0.019	0.001	0.021	0.002	0.011	0.004
11/03/05	0	36.97	-76.02	0.198	0.025	0.137	0.006	0.156	0.016	0.034	0.003	0.011	0.001
11/03/05	14.2	36.97	-76.02	0.058	0.007	0.007	0.001	0.020	0.001	0.034	0.003	0.012	0.000
04/20/06	0	36.91	-75.88	0.113	0.006	0.012	0.000	0.013	0.017	0.034	0.000	0.029	0.002
04/20/06	10	36.91	-75.88	0.108	0.034	0.014	0.000	0.016	0.010	0.022	0.010	0.015	0.000
05/08/06	2	36.97	-76.02	0.085	0.004	0.037	0.002	0.030	0.000	0.023	0.000	0.032	0.006
05/08/06	17	36.97	-76.02	0.065	0.004	0.024	0.002	0.021	0.002	0.020	0.001	0.013	0.001
07/02/06	2	36.97	-76.02	0.100	0.004	0.045	0.003	0.033	0.000	0.009	0.000	0.013	0.000
07/02/06	6	36.97	-76.02	0.080	0.005	0.029	0.001	0.013	0.001	0.013	0.000	0.006	0.000
08/24/06	2	36.91	-75.92	0.094	0.000	0.024	0.002	0.077	0.008	n.d.	n.d.	0.019	0.001
08/24/06	6	36.91	-75.92	0.094	0.000	0.034	0.000	0.037	0.007	0.121	0.041	0.023	0.003
09/06/06	1	36.97	-76.02	0.139	0.001	0.134	0.002	0.030	0.000	0.092	0.013	0.024	0.001
09/06/06	14.5	36.97	-76.02	0.101	0.010	0.002	0.000	0.002	0.000	0.018	0.003	0.021	0.003
10/31/06	2	36.97	-76.02	0.070	0.003	0.001	0.000	0.007	0.000	0.014	0.001	0.005	0.000
10/31/06	6	36.97	-76.02	0.047	0.002	0.001	0.000	0.003	0.000	0.009	0.001	0.005	0.000
11/28/06	1	36.97	-76.02	0.038	0.004	0.009	0.002	0.037	0.006	0.025	0.000	0.003	0.001
11/28/06	4	36.97	-76.02	0.042	0.000	0.005	0.002	0.012	0.005	0.017	0.005	0.002	0.000

Appendix Table A.5. Continued.

Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea N	+/-	DFAA N	+/-
BM													
03/19/07	1	36.97	-76.02	0.057	0.012	0.029	0.005	0.041	0.006	0.054	0.003	0.006	0.006
03/19/07	15	36.97	-76.02	0.033	0.004	0.013	0.000	0.015	0.003	0.028	0.003	0.003	0.002
04/23/07	1.5	36.97	-76.02	0.167	0.023	0.032	0.002	0.043	0.002	n.d.	n.d.	0.046	0.009
04/23/07	5	36.97	-76.02	0.119	0.021	0.015	0.002	0.018	0.000	n.d.	n.d.	0.019	0.004
07/03/07	1.5	36.97	-76.02	0.083	0.004	0.065	0.001	0.043	0.000	0.042	0.001	0.023	0.028
07/03/07	n.d.	36.97	-76.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	1.5	36.97	-76.02	0.061	0.001	0.045	0.007	0.032	0.001	0.029	0.000	0.066	0.044
08/16/07	n.d.	36.97	-76.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
PL1													
03/30/05	n.d.	36.90	-75.91	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/30/05	n.d.	36.90	-75.91	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	0	36.89	-75.91	0.227	0.026	0.003	0.000	0.091	0.025	0.041	0.003	0.032	0.027
05/27/05	7	36.89	-75.91	0.081	0.006	0.004	0.000	0.004	0.000	0.019	0.000	0.008	0.002
06/21/05	0	36.89	-75.91	0.268	0.000	0.066	0.003	0.038	0.000	0.132	0.003	0.126	0.003
06/21/05	8	36.89	-75.91	0.186	0.010	0.013	0.002	0.033	0.002	0.035	0.001	0.029	0.003
07/27/05	2	36.90	-75.91	0.280	0.015	0.055	0.003	0.190	0.008	0.040	0.000	0.034	0.005
07/27/05	8	36.90	-75.91	0.233	0.022	0.044	0.001	0.101	0.006	0.049	0.003	0.018	0.000
11/03/05	0	36.90	-75.91	0.132	0.009	0.119	0.020	0.135	0.030	0.024	0.002	0.010	0.001
11/03/05	3	36.90	-75.91	0.123	0.016	0.077	0.001	0.109	0.019	0.014	0.001	0.008	0.000
04/20/06	1	36.91	-75.80	0.127	0.000	0.020	0.000	0.020	0.009	0.027	0.000	0.027	0.009
04/20/06	13.4	36.91	-75.80	0.118	0.047	0.021	0.006	0.021	0.001	0.022	0.000	0.007	0.000
05/08/06	1.5	36.90	-75.91	0.087	0.010	0.045	0.006	0.019	0.002	0.114	0.018	0.047	0.005
05/08/06	12	36.90	-75.91	0.082	0.003	0.036	0.001	0.018	0.000	0.144	0.011	0.026	0.001

Appendix Table A.5. Continued.

Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea N	+/-	DFAA N	+/-
PL1													
07/02/06	2	36.90	-75.91	0.094	0.008	0.054	0.013	0.038	0.006	0.047	0.005	0.040	0.006
07/02/06	5	36.90	-75.91	0.085	0.003	0.028	0.000	0.025	0.003	0.032	0.000	0.012	0.000
08/24/06	0	36.89	-75.73	0.133	0.013	0.062	0.004	0.039	0.002	0.166	0.004	0.017	0.007
08/24/06	2	36.89	-75.73	0.073	0.058	0.020	0.029	0.038	0.002	0.148	0.075	0.020	0.003
09/06/06	1.3	36.90	-75.91	0.128	0.002	0.109	0.010	0.028	0.002	0.133	0.022	0.017	0.002
09/06/06	16.2	36.90	-75.91	0.056	0.003	0.001	0.000	0.002	0.000	0.004	0.000	0.013	0.001
10/31/06	2	36.90	-75.91	0.132	0.001	0.009	0.000	0.026	0.000	0.035	0.006	0.009	0.000
10/31/06	6	36.90	-75.91	0.049	0.002	0.001	0.000	0.004	0.000	0.008	0.002	0.004	0.000
11/28/06	1	36.90	-75.91	0.104	0.008	0.004	0.000	0.066	0.007	0.020	0.002	0.004	0.000
11/28/06	3.1	36.90	-75.91	0.065	0.001	0.001	0.000	0.007	0.000	0.010	0.001	0.005	0.001
03/19/07	1.2	36.92	-76.01	0.052	0.001	0.029	0.006	0.026	0.001	0.042	0.004	0.006	0.000
03/19/07	6	36.92	-76.01	0.047	0.003	0.019	0.001	0.017	0.003	0.022	0.000	0.005	0.000
04/23/07	1	36.92	-76.01	0.116	0.005	0.021	0.002	0.013	0.003	n.d.	n.d.	0.015	0.002
04/23/07	4.5	36.92	-76.01	0.106	0.000	0.015	0.001	0.011	0.001	n.d.	n.d.	0.006	0.001
07/03/07	1.5	36.92	-76.01	0.015	0.001	0.012	0.001	0.009	0.001	0.012	0.001	0.025	0.024
07/03/07	n.d.	36.92	-76.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	1.5	36.92	-76.01	0.110	0.000	0.031	0.000	0.020	0.002	0.033	0.004	0.069	0.053
08/16/07	n.d.	36.92	-76.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
PL2													
03/30/05	2	36.80	-75.86	0.340	0.044	0.003	0.001	0.039	0.021	0.024	0.003	0.110	0.004
03/30/05	13	36.80	-75.86	0.056	0.002	0.002	0.001	0.012	0.010	0.010	0.000	0.115	0.001
05/27/05	0	36.80	-75.86	0.168	0.004	0.003	0.000	0.120	0.101	0.033	0.002	0.039	0.002
05/27/05	8	36.80	-75.86	0.122	0.006	0.007	0.001	0.005	0.001	0.054	0.001	0.013	0.000

Appendix Table A.5. Continued.

				PL2									
Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea N	+/-	DFAA N	+/-
06/21/05	0	36.80	-75.86	0.363	0.008	0.074	0.003	0.035	0.003	0.108	0.021	0.108	0.005
06/21/05	14.8	36.80	-75.86	0.109	0.002	0.002	0.000	0.003	0.000	0.022	0.001	0.052	0.001
07/27/05	2	36.80	-75.86	0.325	0.016	0.031	0.001	0.143	0.006	0.079	0.018	0.049	0.000
07/27/05	15.6	36.80	-75.86	0.329	0.017	0.021	0.003	0.089	0.009	0.044	0.011	0.028	0.001
11/03/05	0	36.80	-75.86	0.211	0.014	0.149	0.004	0.068	0.001	0.054	0.006	0.013	0.002
11/03/05	5	36.80	-75.86	0.174	0.009	0.031	0.000	0.017	0.001	0.063	0.003	0.008	0.000
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.80	-75.86	0.076	0.003	0.015	0.001	0.000	0.000	0.000	0.000	0.000	0.000
05/08/06	16	36.80	-75.86	0.055	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
07/02/06	2	36.80	-75.86	0.081	0.002	0.045	0.001	0.029	0.001	0.036	0.000	0.051	0.002
07/02/06	6	36.80	-75.86	0.051	0.003	0.038	0.004	0.021	0.003	0.027	0.003	0.016	0.002
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	1	36.80	-75.86	0.201	0.002	0.043	0.003	0.060	0.003	0.083	0.006	0.028	0.007
09/06/06	15.2	36.80	-75.86	0.110	0.006	0.004	0.001	0.003	0.000	0.012	0.005	0.020	0.001
10/31/06	2	36.80	-75.86	0.062	0.001	0.009	0.001	0.010	0.000	0.012	0.001	0.004	0.000
10/31/06	5	36.80	-75.86	0.050	0.000	0.004	0.000	0.004	0.000	0.011	0.002	0.002	0.000
11/28/06	1	36.80	-75.86	0.072	0.003	0.007	0.000	0.056	0.004	0.027	0.002	0.004	0.001
11/28/06	3.3	36.80	-75.86	0.039	0.004	0.001	0.000	0.006	0.000	0.008	0.000	0.002	0.000
03/19/07	1	36.80	-75.86	0.036	n.d.	0.047	0.005	0.009	0.001	0.020	0.003	0.004	0.003
03/19/07	15.5	36.80	-75.86	0.045	0.003	0.037	0.000	0.031	0.004	0.020	0.002	0.005	0.000
04/23/07	1.5	36.80	-75.86	0.265	0.002	0.027	0.003	0.011	0.000	n.d.	n.d.	0.020	0.001
04/23/07	6	36.80	-75.86	0.119	0.005	0.009	0.001	0.014	0.002	n.d.	n.d.	0.006	0.001

Appendix Table A.5. Continued.

Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea N	+/-	DFAA N	+/-
							PL2						
07/03/07	1.5	36.80	-75.86	0.075	0.005	0.053	0.001	0.020	0.001	0.109	0.000	0.019	0.014
07/03/07	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	1.5	36.80	-75.86	0.122	0.008	0.016	0.004	0.005	0.003	0.006	0.001	0.028	0.035
08/16/07	n.d.	36.80	-75.86	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
							PL3						
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/30/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/27/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.68	-75.6	0.168	0.008	0.019	0.000	0.078	0.004	0.024	0.007	0.021	0.000
07/27/05	7.6	36.68	-75.6	0.151	0.006	0.013	0.001	0.054	0.006	0.023	0.000	0.025	0.002
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/03/05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	2	36.67	-75.8	0.016	0.001	0.039	0.006	0.016	0.001	0.035	0.000	0.068	0.004
05/08/06	17	36.67	-75.8	0.018	0.001	0.035	0.002	0.017	0.003	0.050	0.001	0.052	0.001
07/02/06	2	36.67	-75.8	0.107	0.002	0.055	0.001	0.027	0.002	0.020	0.001	0.041	0.001
07/02/06	10	36.67	-75.8	0.068	0.004	0.036	0.001	0.013	0.002	0.023	0.000	0.010	0.001
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/24/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix Table A.5. Continued.

Date	Depth (m)	Lat.	Lon.	NH4+	+/-	NO2-	+/-	NO3-	+/-	Urea N	+/-	DFAA N	+/-
							PL3						
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/06/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/31/06	2	36.68	-75.76	0.031	0.001	0.011	0.000	0.022	0.000	0.014	0.002	0.002	0.000
10/31/06	5	36.68	-75.76	0.029	0.002	0.011	0.000	0.011	0.001	0.020	0.011	0.003	0.001
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/28/06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
03/19/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/23/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/03/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
							CLT						
03/30/05	4.5	36.91	-75.71	0.172	0.031	0.018	0.001	0.052	0.019	0.090	0.015	0.012	0.002
03/30/05	18.5	36.91	-75.71	0.051	0.007	0.007	0.001	0.017	0.001	0.024	0.001	0.019	0.005
05/27/05	0	36.91	-75.72	0.182	0.039	0.009	0.000	0.027	0.005	0.010	0.001	0.069	0.011
05/27/05	6	36.91	-75.72	0.032	0.004	0.011	0.003	0.008	0.001	0.040	0.004	0.004	0.003
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
06/21/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/27/05	2	36.91	-75.71	0.305	0.070	0.024	0.001	0.088	0.010	0.067	0.009	0.042	0.006
07/27/05	12.3	36.91	-75.71	0.225	0.025	0.030	0.000	0.046	0.001	0.046	0.000	0.012	0.001

Appendix Table A.5. Continued.

				CLT									
Date	Depth (m)	Lat.	Lon.	NH_4^+	+/-	NO_2^-	+/-	NO_3^-	+/-	Urea N	+/-	DFAA N	+/-
11/03/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11/03/05	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
04/20/06	0	36.91	-75.71	0.120	0.013	0.012	0.003	0.024	0.001	0.038	0.002	0.017	0.000
04/20/06	10.5	36.91	-75.71	0.137	0.033	0.014	0.005	0.029	0.001	0.014	0.001	0.008	0.001
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
05/08/06	n.d.	36.91	-75.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
07/02/06	2	36.91	-75.71	0.125	0.003	0.056	0.000	0.046	0.000	0.041	0.003	0.036	0.001
07/02/06	5.5	36.91	-75.71	0.111	0.006	0.073	0.001	0.034	0.001	0.036	0.001	0.063	0.002
08/24/06	0	36.91	-75.71	0.057	0.012	0.008	0.003	0.003	0.002	0.044	0.033	0.004	0.001
08/24/06	0	36.91	-75.71	0.063	0.011	0.004	0.001	0.007	0.002	0.025	0.000	0.002	0.000
09/06/06	1	36.91	-75.71	0.248	0.025	0.035	0.000	0.117	0.015	0.102	0.023	0.014	0.000
09/06/06	7	36.91	-75.71	0.115	0.003	0.003	0.000	0.004	0.000	0.063	0.007	0.011	0.000
10/31/06	2	36.91	-75.71	0.025	0.002	0.001	0.000	0.003	0.001	0.003	0.000	0.002	0.000
10/31/06	6	36.91	-75.71	0.021	0.011	0.003	0.000	0.007	0.000	0.002	0.000	0.003	0.000
11/28/06	1	36.91	-75.71	0.163	0.003	0.010	0.000	0.067	0.001	0.032	0.000	0.004	0.000
11/28/06	5	36.91	-75.71	0.084	0.011	0.006	0.000	0.037	0.003	0.018	0.000	0.010	0.001
03/19/07	1	36.91	-75.72	0.022	0.003	0.006	0.000	0.008	0.001	0.014	0.002	0.002	0.000
03/19/07	12	36.91	-75.72	0.026	0.002	0.006	0.002	0.008	0.001	0.010	0.002	0.001	0.000
04/23/07	1	36.91	-75.72	0.108	0.003	0.028	0.001	0.038	0.004	n.d.	n.d.	0.035	0.001
04/23/07	12	36.91	-75.72	0.026	0.004	0.003	0.000	0.004	0.001	n.d.	n.d.	0.005	0.000
07/03/07	1.5	36.91	-75.72	0.028	0.003	0.003	0.002	0.003	0.000	0.018	0.003	0.003	0.000
07/03/07	n.d.	36.91	-75.72	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
08/16/07	n.d.	36.91	-75.72	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
8/16//07	1.5	36.91	-75.72	0.088	0.013	0.003	0.005	0.014	0.005	0.034	0.002	0.041	0.009

Appendix Table A.6. Pearon's product moment correlation for all parameters in the plume. R = regression coefficient, $p < 0.05$ is significant, and n = sample number.

		T	S	Chl *a*	PN	PC	DIC	Alkalinity	NH_4^+	NO_2^-	NO_3^-	Urea	DFAA N	DIN	DON	TDN	PO_4^{3-}	SiO_4^+
		(oC)		(μg chl L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(mmol L^{-1})		(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})
Freshwater flow	R	-0.493	-0.134	0.381	0.293	0.222	-0.0298	0.0673	-0.0203	0.0248	0.149	-0.249	-0.0524	0.0969	0.0605	0.0771	0.00487	0.0156
($m^3 s^{-1}$)	p	3.31E-09	0.132	0.00000894	0.000837	0.0122	0.774	0.515	0.821	0.782	0.0926	0.00453	0.569	0.276	0.497	0.387	0.956	0.861
	n	128	128	128	127	127	96	96	127	128	128	128	120	128	128	128	128	128
T	R		0.0302	-0.353	-0.0706	-0.0403	0.00478	0.0595	0.0577	0.0203	-0.189	0.253	-0.0189	-0.0922	-0.321	-0.322	-0.0458	0.324
(oC)	p		0.735	0.0000441	0.43	0.653	0.963	0.565	0.519	0.82	0.0327	0.00397	0.837	0.301	0.000224	0.000206	0.608	0.000192
	n		128	128	127	127	96	96	127	128	128	128	120	128	128	128	128	128
S	R			-0.429	-0.448	-0.319	0.557	0.636	-0.00373	-0.0309	-0.35	-0.0465	0.0656	-0.239	-0.142	-0.183	0.0321	-0.275
	p			0.000000436	0.000000132	0.000258	3.69E-09	3.22E-12	0.967	0.73	0.0000504	0.602	0.476	0.00651	0.111	0.0389	0.719	0.0017
	n			128	127	127	96	96	127	128	128	128	120	128	128	128	128	128
Chl *a*	R				0.713	0.647	-0.337	-0.26	0.0844	0.414	0.411	0.0197	0.0307	0.399	0.327	0.391	0.189	0.349
(μg chl L^{-1})	p				5.74E-21	2.10E-16	0.000785	0.0106	0.345	0.00000119	0.00000142	0.825	0.74	0.00000302	0.000162	0.00000501	0.0325	0.0000534
	n				127	127	96	96	127	128	128	128	120	128	128	128	128	128
PN	R					0.931	-0.33	-0.353	0.0761	0.25	0.161	-0.141	-0.03	0.198	0.212	0.241	0.0939	0.378
(μmol L^{-1})	p					1.40E-56	0.0011	0.000442	0.397	0.00454	0.0702	0.114	0.746	0.0257	0.0168	0.00638	0.294	0.0000118
	n					127	95	95	126	127	127	127	119	127	127	127	127	127
PC	R						-0.185	-0.192	0.212	0.241	0.125	-0.158	0.00779	0.233	0.263	0.296	0.162	0.358
(μmol L^{-1})	p						0.0723	0.0617	0.0171	0.00635	0.161	0.0766	0.933	0.00842	0.00282	0.000719	0.0688	0.000035
	n						95	95	126	127	127	127	119	127	127	127	127	127
DIC	R							0.72	-0.0384	-0.0578	-0.315	-0.194	0.0652	-0.24	-0.223	-0.26	-0.0811	-0.173
(mmol L^{-1})	p							1.32E-16	0.71	0.576	0.00178	0.0579	0.528	0.0183	0.0287	0.0104	0.432	0.0912
	n							96	96	96	96	96	96	96	96	96	96	96
Alkalinity	R								0.0676	0.164	-0.215	0.0364	0.0183	-0.0743	0.0141	-0.00322	-0.0233	0.0528
	p								0.513	0.111	0.0358	0.725	0.86	0.472	0.892	0.975	0.822	0.609
	n								96	96	96	96	96	96	96	96	96	96
NH_4^+	R									0.278	0.255	0.0562	0.00597	0.695	0.0254	0.165	0.626	0.39
(μmol L^{-1})	p									0.00154	0.00382	0.53	0.949	1.33E-19	0.777	0.0635	3.78E-15	5.99E-06
	n									127	127	127	119	127	127	127	127	127
NO_2^-	R										0.362	0.0317	0.0209	0.581	0.215	0.321	0.13	0.593
(μmol L^{-1})	p										0.0000274	0.723	0.821	6.45E-13	0.015	0.000218	0.143	1.63E-13
	n										128	128	120	128	128	128	128	128
NO_3^-	R											-0.0562	-0.0588	0.845	0.154	0.318	0.122	0.491
(μmol L^{-1})	p											0.529	0.524	4.04E-36	0.0823	0.000258	0.169	3.89E-09
	n											128	120	128	128	128	128	128
Urea	R												0.136	-0.00912	-0.0874	-0.0846	0.241	0.153
(μmol L^{-1})	p												0.138	0.919	0.327	0.342	0.00611	0.0839
	n												120	128	128	128	128	128
DFAA N	R													-0.0534	-0.0652	-0.0717	-0.0333	-0.0756
(μmol L^{-1})	p													0.563	0.479	0.436	0.718	0.412
	n													120	120	120	120	120
DIN	R														0.161	0.356	0.402	0.631
(μmol L^{-1})	p														0.0686	0.0000372	0.00000264	1.49E-15
	n														128	128	128	128
DON	R															0.98	-0.172	0.0954
(μmol L^{-1})	p															8.07E-90	0.0526	0.284
	n															128	128	128
TDN	R																-0.081	0.218
(μmol L^{-1})	p																0.363	0.0133
	n																128	128
PO_4^{3-}	R																	0.0932
(μmol L^{-1})	p																	0.295
	n																	128

Appendix Table 6. Continued.

HCO_3^- daily (μmol L^{-1} d^{-1})	HCO_3^- Chl *a* normalized (μmol μg chl^{-1} d^{-1})	NH_4^+ volumetric (μmol L^{-1} h^{-1})	NO_2^- volumetric (μmol L^{-1} h^{-1})	NO_3^- volumetric (μmol L^{-1} h^{-1})	Urea volumetric (μmol L^{-1} h^{-1})	DFAA N volumetric (μmol L^{-1} h^{-1})	TN volumetric (μmol L^{-1} h^{-1})	NH_4^+ Chl *a* normalized (μmol μg chl^{-1} h^{-1})	NO_2^- Chl a normalized (μmol μg chl^{-1} h^{-1})	NO_3^- Chl a normalized (μmol μg chl^{-1} h^{-1})	Urea Chl a normalized (μmol μg chl^{-1} h^{-1})	DFAA N Chl a normalized (μmol μg chl^{-1} h^{-1})	TN Chl a normalized (μmol μg chl^{-1} h^{-1})
-0.206 0.0265 116	-0.365 0.000057 116	-0.389 0.0000177 115	-0.133 0.158 115	-0.225 0.0158 115	-0.397 0.0000125 114	-0.254 0.00607 115	-0.277 0.00273 115	-0.397 0.0000104 116	-0.228 0.0136 116	-0.274 0.00296 116	-0.354 0.0000963 116	-0.333 0.000265 116	-0.412 0.0000428 116
0.0755 0.42 116	0.275 0.00285 116	0.351 0.000123 115	0.358 0.000086 115	0.254 0.00612 115	0.348 0.000147 114	0.256 0.00572 115	0.39 0.0000168 115	0.383 0.000022 116	0.485 3.45E-08 116	0.338 0.000204 116	0.344 0.000159 116	0.374 0.0000355 116	0.44 0.000000787 116
-0.167 0.0726 116	-0.0497 0.596 116	0.0998 0.289 115	0.0732 0.437 115	-0.0334 0.723 115	0.0985 0.297 114	-0.0176 0.852 115	-0.223 0.0168 115	0.127 0.173 116	0.0676 0.471 116	0.028 0.765 116	0.115 0.218 116	0.015 0.873 116	0.113 0.229 116
0.358 0.0000783 116	-0.182 0.0506 116	-0.398 0.0000116 115	-0.0569 0.546 115	-0.113 0.228 115	-0.395 0.0000139 114	-0.302 0.00103 115	0.0721 0.444 115	-0.561 6.00E-11 116	-0.433 0.00000121 116	-0.37 0.0000425 116	-0.455 0.000000283 116	-0.506 6.62E-09 116	-0.581 8.25E-12 116
0.354 0.000105 115	0.0773 0.412 115	-0.36 0.000078 115	0.0551 0.558 115	-0.142 0.131 115	-0.271 0.00353 114	-0.196 0.0355 115	0.349 0.000138 114	-0.373 0.0000407 115	-0.0763 0.418 115	-0.228 0.0141 115	-0.282 0.00225 115	-0.187 0.0458 115	-0.343 0.000177 115
0.283 0.0022 115	0.0911 0.333 115	-0.328 0.000347 115	0.0617 0.512 115	-0.103 0.274 115	-0.243 0.00933 114	-0.195 0.037 115	0.311 0.000756 114	-0.328 0.000345 115	-0.0533 0.571 115	-0.152 0.092 115	-0.258 0.00531 115	-0.176 0.0594 115	-0.297 0.00127 115
-0.153 0.144 92	0.00918 0.931 92	-0.0702 0.508 91	0.0762 0.473 91	-0.0943 0.374 91	-0.0322 0.763 90	-0.0103 0.923 91	-0.27 0.00966 91	-0.0328 0.756 92	0.0196 0.853 92	-0.00723 0.945 92	-0.0354 0.738 92	-0.0305 0.773 92	-0.0307 0.771 92
-0.123 0.243 92	-0.0208 0.844 92	-0.0479 0.652 91	0.201 0.0565 91	-0.0353 0.74 91	0.0865 0.418 90	-0.195 0.0634 91	-0.278 0.00752 91	0.0184 0.862 92	0.0977 0.354 92	0.0499 0.637 92	0.0948 0.369 92	-0.161 0.126 92	0.0371 0.726 92
0.0381 0.684 116	-0.0153 0.87 116	-0.00239 0.98 115	-0.246 0.00805 115	-0.0877 0.351 115	-0.161 0.0869 114	-0.102 0.278 115	-0.0505 0.592 115	-0.0568 0.544 116	-0.256 0.00563 116	-0.094 0.316 116	-0.133 0.153 116	-0.142 0.129 116	-0.12 0.198 116
0.484 3.61E-08 116	0.0682 0.467 116	-0.146 0.12 115	0.418 0.00000327 115	0.0859 0.361 115	-0.118 0.212 114	-0.231 0.0128 115	0.141 0.132 115	-0.214 0.0208 116	0.0112 0.905 116	-0.125 0.181 116	-0.142 0.129 116	-0.27 0.00342 116	-0.202 0.0293 116
0.168 0.0722 116	-0.0652 0.487 116	-0.128 0.172 115	-0.228 0.0142 115	0.126 0.179 115	-0.2 0.0328 114	-0.237 0.0108 115	-0.0739 0.433 115	-0.194 0.0366 116	-0.31 0.000707 116	-0.0607 0.518 116	-0.192 0.0393 116	-0.276 0.00271 116	-0.223 0.0162 116
-0.176 0.0585 116	-0.282 0.00213 116	-0.172 0.0661 115	-0.0988 0.294 115	-0.209 0.0248 115	0.171 0.0694 114	0.0668 0.478 115	-0.204 0.0285 115	-0.162 0.0827 116	-0.121 0.194 116	-0.191 0.0398 116	0.123 0.187 116	-0.0806 0.39 116	-0.105 0.26 116
0.0801 0.41 108	0.0766 0.431 108	0.123 0.208 107	0.0801 0.412 107	-0.000919 0.993 107	0.0912 0.352 106	0.444 0.00000164 107	0.094 0.335 107	0.0421 0.665 108	0.0047 0.961 108	-0.0258 0.791 108	0.0228 0.814 108	0.361 0.000126 108	0.0634 0.515 108
0.232 0.0123 116	-0.0352 0.708 116	-0.117 0.214 115	-0.172 0.0658 115	0.0589 0.532 115	-0.231 0.0132 114	-0.252 0.00659 115	-0.0417 0.658 115	-0.2 0.0312 116	-0.319 0.000482 116	-0.111 0.235 116	-0.218 0.0185 116	-0.305 0.00087 116	-0.246 0.00779 116
0.152 0.104 116	0.108 0.25 116	-0.0235 0.803 115	0.0486 0.606 115	0.14 0.136 115	-0.165 0.0802 114	-0.153 0.104 115	0.029 0.759 115	-0.0221 0.814 116	-0.0834 0.374 116	0.0905 0.334 116	-0.174 0.0612 116	-0.118 0.206 116	-0.0636 0.498 116
0.191 0.0397 116	0.0951 0.31 116	-0.0462 0.624 115	0.011 0.907 115	0.145 0.122 115	-0.204 0.0297 114	-0.196 0.0354 115	0.0191 0.84 115	-0.0619 0.509 116	-0.144 0.122 116	0.0632 0.5 116	-0.21 0.0236 116	-0.175 0.0606 116	-0.111 0.237 116
-0.0266 0.777 116	-0.158 0.0909 116	-0.0485 0.607 115	-0.317 0.000564 115	-0.0976 0.299 115	-0.133 0.158 114	-0.0722 0.443 115	-0.0876 0.352 115	-0.186 0.0457 116	-0.382 0.0000238 116	-0.179 0.0545 116	-0.162 0.0828 116	-0.256 0.00561 116	-0.235 0.011 116
0.21 0.0234 116	-0.056 0.551 116	-0.263 0.00458 115	0.167 0.0738 115	-0.0474 0.615 115	-0.131 0.166 114	-0.211 0.0233 115	0.105 0.265 115	-0.267 0.00376 116	-0.0137 0.884 116	-0.135 0.149 116	-0.16 0.0871 116	-0.213 0.0216 116	-0.233 0.0117 116
	0.626 5.81E-14 116	0.0704 0.455 115	0.372 0.0000425 115	0.242 0.00905 115	-0.00526 0.956 114	-0.023 0.808 115	0.517 3.27E-09 115	-0.0321 0.733 116	0.0952 0.31 116	0.0611 0.515 116	-0.0761 0.417 116	0.00369 0.969 116	-0.0181 0.847 116
		0.398 0.0000105 115	0.314 0.000632 115	0.446 0.000000586 115	0.249 0.00749 114	0.236 0.011 115	0.569 3.24E-11 115	0.472 8.71E-08 116	0.404 0.00000696 116	0.536 5.52E-10 116	0.248 0.00731 116	0.471 9.37E-08 116	0.499 1.17E-08 116
			0.292 0.00154 115	0.583 7.73E-12 115	0.388 0.0000203 114	0.394 0.0000131 115	0.547 3.05E-10 114	0.858 1.58E-34 115	0.42 0.00000302 115	0.642 1.03E-14 115	0.387 0.0000191 115	0.489 2.92E-08 115	0.766 2.08E-23 115
				0.364 0.0000635 115	0.383 0.0000256 114	0.134 0.152 115	0.57 3.74E-11 114	0.253 0.00636 115	0.762 4.36E-23 115	0.3 0.00111 115	0.295 0.00137 115	0.231 0.0129 115	0.359 0.0000829 115
					0.313 0.000708 114	0.157 0.0932 115	0.597 2.26E-12 114	0.509 6.34E-09 115	0.343 0.000171 115	0.878 5.73E-38 115	0.228 0.0141 115	0.244 0.00864 115	0.542 3.82E-10 115
						0.195 0.0378 114	0.373 0.000044 114	0.514 5.06E-09 114	0.622 1.45E-13 114	0.44 0.000000965 114	0.901 2.31E-42 114	0.35 0.000135 114	0.688 2.77E-17 114
							0.313 0.000686 114	0.33 0.00032 115	0.253 0.00641 115	0.216 0.0206 115	0.155 0.0982 115	0.845 1.85E-32 115	0.368 0.0000532 115
								0.446 0.000000588 115	0.537 5.95E-10 115	0.54 4.55E-10 115	0.277 0.00272 115	0.417 0.00000338 115	0.498 1.52E-08 115
									0.594 1.99E-12 116	0.738 3.48E-21 116	0.648 3.63E-15 116	0.614 2.25E-13 116	0.958 1.03E-63 116
										0.506 6.92E-09 116	0.667 2.87E-16 116	0.541 3.5E-10 116	0.733 8.35E-21 116
											0.422 0.00000238 116	0.451 0.000000385 116	0.775 1.74E-24 116
												0.398 0.00000968 116	0.795 1.74E-26 116
													0.669 2.22E-16 116

Appendix Table B.1. 2005 – 2006 NH_4^+, NO_2^-, NO_3^-, Urea, DFAA, DON, and DIN concentrations for all stations, regions, dates, and depths. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available, b.l.d.= below the limit of detection (NH_4^+: 0.05; NO_2^-: 0.02; NO_3^-: 0.02; Urea: 0.05; DFAA: 0.03).

Date	Depth (m)	Region	NH_4^+ (μmol L^{-1})	+/-	NO_2^- (μmol L^{-1})	+/-	NO_3^- (μmol L^{-1})	+/-	Urea N (μmol L^{-1})	+/-	DFAA N (μmol L^{-1})	+/-	DON (μmol L^{-1})	+/-	DIN (μmol L^{-1})	+/-
3/30/2005	4.5	PL	0.76	0.01	0.18	0.01	0.46	0.01	0.76	0.05	0.21	0.08	19.74	0.02	1.40	0.02
3/30/2005	18.2	PL	0.74	0.01	0.18	0.00	0.30	0.06	0.39	0.04	0.39	0.06	12.36	0.06	1.22	0.06
3/30/2005	2.0	PL	0.76	0.02	0.15	0.00	0.24	0.04	0.87	0.03	0.45	0.05	13.28	0.05	1.15	0.05
3/30/2005	4.4	PL	0.86	0.04	0.17	0.03	0.24	0.08	0.62	0.01	0.44	0.01	15.30	0.09	1.27	0.09
3/30/2005	5.0	PL	0.84	0.05	0.06	0.00	0.28	0.03	0.71	0.06	0.56	0.05	14.89	0.06	1.18	0.06
3/30/2005	15.0	PL	0.84	0.09	0.06	0.00	0.38	0.05	0.24	0.02	0.70	0.07	13.50	0.10	1.28	0.10
3/30/2005	2.0	PL	1.06	0.02	0.06	0.03	0.28	0.03	0.23	0.15	1.70	0.86	10.81	0.04	1.40	0.04
3/30/2005	13.0	PL	0.99	0.33	0.08	0.01	0.25	0.07	0.41	0.01	0.60	0.01	14.26	0.34	1.32	0.34
3/31/2005	2.0	SS	1.00	0.06	b.l.d.	b.l.d.	0.50	0.04	0.10	n.d.	0.29	0.16	15.72	0.07	1.50	0.07
3/31/2005	15.0	SS	1.00	0.04	b.l.d.	b.l.d.	0.47	0.01	0.09	0.05	0.23	0.03	16.59	0.04	1.48	0.04
3/31/2005	5.0	SS	1.33	0.06	0.08	0.04	2.78	0.04	0.28	0.01	0.41	0.04	13.74	0.08	4.19	0.08
3/31/2005	17.0	SS	1.18	0.06	0.07	0.00	2.97	0.05	0.10	0.00	0.43	0.01	13.70	0.08	4.23	0.08
4/1/2005	2.0	MS	1.30	0.03	0.05	0.00	1.29	0.03	b.l.d.	b.l.d.	0.15	0.00	12.28	0.04	2.65	0.04
4/1/2005	53.0	MS	1.70	0.02	0.13	0.06	2.10	0.08	0.39	0.02	0.15	0.02	13.57	0.10	3.93	0.10
4/1/2005	5.0	MS	0.88	0.09	b.l.d.	b.l.d.	0.47	0.00	b.l.d.	b.l.d.	0.60	0.23	23.00	0.10	1.35	0.10
4/1/2005	10.0	MS	0.88	0.03	0.02	0.01	0.45	0.06	0.15	0.01	0.29	0.11	29.72	0.07	1.36	0.07
4/1/2005	2.0	MS	0.86	0.01	0.08	0.00	0.39	0.01	b.l.d.	b.l.d.	0.20	0.06	16.67	0.01	1.33	0.01
4/1/2005	20.8	MS	1.02	0.01	b.l.d.	b.l.d.	0.32	0.02	0.20	0.04	0.20	0.00	15.29	0.02	1.35	0.02
7/26/2005	2.0	PL	0.74	0.02	0.06	0.01	0.25	0.02	0.16	0.01	0.32	0.04	17.59	0.74	1.05	0.03
7/26/2005	12.3	PL	0.75	0.02	0.16	0.01	0.21	0.06	0.16	0.01	0.17	0.02	10.97	2.11	1.12	0.06
7/27/2005	2.0	PL	1.08	0.01	0.17	0.03	0.11	0.06	0.10	0.01	0.20	0.02	21.53	1.24	1.36	0.07
7/27/2005	5.0	PL	0.84	0.02	0.19	0.03	0.24	0.10	0.10	0.03	0.17	0.02	21.97	3.34	1.27	0.11
7/27/2005	2.0	PL	0.82	0.01	0.10	0.01	0.58	0.01	0.07	0.00	0.24	0.04	19.90	0.02	1.50	0.02
7/27/2005	8.0	PL	0.78	0.03	0.16	n.d.	0.29	n.d.	0.10	0.01	0.16	0.04	15.40	n.d.	1.22	n.d.
7/27/2005	2.0	PL	0.81	0.02	0.02	0.01	0.43	0.05	0.14	0.02	0.22	0.00	22.98	3.01	1.25	0.05
7/27/2005	15.6	PL	0.85	0.01	0.07	0.01	0.35	0.03	0.10	0.04	0.13	0.01	12.83	5.19	1.27	0.04

Appendix Table B.1. Continued.

Date	Depth (m)	Region	NH_4^+ (μmol L^{-1})	+/-	NO_2^- (μmol L^{-1})	+/-	NO_3^- (μmol L^{-1})	+/-	Urea N (μmol L^{-1})	+/-	DFAA N (μmol L^{-1})	+/-	DON (μmol L^{-1})	+/-	DIN (μmol L^{-1})	+/-
7/27/2005	2.0	PL	0.72	0.02	0.08	0.02	0.30	0.02	b.l.d.	b.l.d.	0.14	0.00	16.59	2.81	1.10	0.04
7/27/2005	7.6	PL	0.64	0.04	0.07	0.01	0.35	0.07	0.10	0.03	0.13	0.01	12.92	2.66	1.06	0.08
7/28/2005	2.0	SS	0.75	0.01	0.09	0.03	0.32	0.05	0.14	0.03	0.11	0.01	11.51	3.11	1.16	0.06
7/28/2005	40.0	SS	0.80	0.03	0.09	0.01	0.38	0.04	0.35	0.00	0.15	0.02	6.20	0.28	1.27	0.05
7/29/2005	2.0	MS	0.96	0.01	b.l.d.	b.l.d.	0.37	0.04	1.21	0.09	0.91	0.44	13.91	0.51	1.35	0.05
7/29/2005	7.8	MS	0.73	0.02	0.09	0.01	0.31	0.12	0.10	0.10	0.12	0.03	20.18	6.96	1.13	0.12
7/29/2005	2.0	MS	0.78	0.01	0.06	0.01	0.27	0.14	0.19	0.01	0.10	0.00	18.74	2.59	1.11	0.14
7/29/2005	31.2	MS	0.80	0.01	0.05	0.01	0.72	0.01	0.10	0.05	0.13	0.02	8.89	1.14	1.58	0.01
7/29/2005	2.0	MS	0.74	0.01	0.09	0.02	0.34	0.02	0.10	0.00	0.14	0.01	18.09	3.87	1.17	0.03
7/29/2005	11.0	MS	0.76	0.02	0.11	0.02	0.27	0.04	0.10	0.03	0.13	0.02	15.26	3.84	1.14	0.05
7/30/2005	2.0	MS	0.80	0.02	0.03	0.02	0.30	0.02	0.10	0.01	0.14	0.01	16.35	3.40	1.13	0.03
7/30/2005	23.0	MS	1.19	0.04	0.04	0.02	0.16	n.d.	0.08	0.07	0.13	0.02	22.62	n.d.	1.40	n.d.
5/11/2006	2.0	PL	0.43	0.06	0.12	0.00	0.09	0.00	0.10	0.01	0.21	0.04	27.07	0.30	0.64	0.06
5/11/2006	12.0	PL	0.40	0.04	0.12	0.12	0.08	0.12	0.11	0.01	0.16	0.01	9.10	0.17	0.60	0.17
5/11/2006	1.5	PL	0.35	0.04	0.14	0.00	b.l.d.	b.l.d.	0.15	0.02	0.24	0.00	12.89	1.88	0.49	0.04
5/11/2006	16.0	PL	0.34	0.03	0.12	0.13	b.l.d.	b.l.d.	0.26	0.00	0.41	0.23	21.09	0.19	0.47	0.19
5/11/2006	2.0	PL	0.36	0.03	0.12	0.02	b.l.d.	b.l.d.	0.09	0.01	0.24	0.01	14.59	1.84	0.49	0.04
5/11/2006	14.0	PL	0.41	0.02	0.11	0.01	0.02	0.01	0.27	0.01	0.21	0.04	16.37	0.02	0.53	0.02
5/11/2006	2.0	PL	0.39	0.03	0.12	0.00	b.l.d.	b.l.d.	0.14	0.02	0.23	0.01	18.05	0.18	0.51	0.03
5/11/2006	17.0	PL	0.31	0.02	0.13	0.02	0.04	0.02	0.29	0.03	0.25	0.04	20.71	0.03	0.48	0.03
5/10/2006	1.5	MS	0.37	0.04	0.12	0.07	0.33	0.09	0.11	0.08	0.21	0.05	4.17	1.20	0.82	0.12
5/10/2006	20.2	MS	0.34	0.02	0.28	0.03	0.23	0.08	0.16	0.02	0.20	0.02	3.38	0.09	0.84	0.09
5/10/2006	2.0	MS	0.31	0.02	0.11	0.00	0.04	0.03	0.09	0.02	0.18	0.02	4.65	0.05	0.46	0.04
5/10/2006	17.7	MS	0.42	0.02	0.26	0.02	2.09	0.04	0.31	0.00	0.17	0.01	4.52	0.04	2.77	0.04
5/10/2006	1.9	MS	0.35	0.04	0.05	0.01	0.06	0.02	0.15	0.02	0.17	0.00	4.04	0.38	0.46	0.04
5/10/2006	26.6	MS	0.44	0.10	0.10	0.02	0.06	0.03	0.32	0.06	0.20	0.06	4.05	0.10	0.60	0.10
5/12/2006	2.0	MS	0.31	0.00	0.09	0.01	0.09	0.02	0.36	0.01	0.28	0.03	18.89	0.04	0.49	0.02
5/12/2006	23.0	MS	0.34	0.01	0.03	0.01	0.12	0.01	0.15	0.00	0.14	0.04	21.93	0.02	0.48	0.02

Appendix Table B.1. Continued.

Date	Depth (m)	Region	NH_4^+ (μmol L^{-1})	+/-	NO_2^- (μmol L^{-1})	+/-	NO_3^- (μmol L^{-1})	+/-	Urea N (μmol L^{-1})	+/-	DFAA N (μmol L^{-1})	+/-	DON (μmol L^{-1})	+/-	DIN (μmol L^{-1})	+/-
5/12/2006	2.0	MS	0.30	0.01	0.08	0.00	0.11	0.01	0.27	0.03	0.16	0.08	19.31	1.87	0.49	0.02
5/12/2006	9.0	MS	0.29	0.02	0.10	0.03	0.09	0.05	0.19	n.d.	0.14	0.05	19.32	0.06	0.48	0.06
5/12/2006	2.0	MS	0.34	0.03	0.20	0.09	b.l.d.	b.l.d.	0.23	0.01	0.17	0.00	24.44	0.25	0.55	0.13
5/12/2006	29.0	MS	0.32	0.03	0.19	0.02	0.08	0.03	0.19	0.03	0.21	0.05	17.86	0.05	0.59	0.05
5/12/2006	2.0	MS	0.29	0.01	0.04	0.00	0.08	0.01	0.26	0.02	0.16	0.02	23.11	0.90	0.41	0.02
5/12/2006	5.0	MS	0.29	0.03	0.18	0.01	0.02	0.03	0.49	0.07	0.15	0.01	23.02	0.04	0.50	0.04
5/9/2006	2.0	PL	0.31	0.05	0.13	0.00	0.03	0.01	0.17	0.01	0.24	0.12	7.06	0.23	0.47	0.05
5/9/2006	5.0	PL	0.39	0.02	0.13	0.00	0.05	0.00	0.22	0.02	0.17	0.00	11.21	0.02	0.58	0.02
5/9/2006	1.5	PL	0.32	0.02	0.13	0.01	0.04	0.01	0.18	0.03	0.22	0.07	9.93	0.99	0.49	0.03
5/9/2006	10.0	PL	0.33	0.08	0.13	0.00	0.02	0.01	0.12	0.02	0.21	0.01	4.71	0.08	0.47	0.08
7/4/2006	2.0	PL	0.34	0.03	0.11	0.02	0.07	0.02	0.18	0.02	0.10	0.24	10.35	0.81	0.51	0.04
7/4/2006	5.5	PL	0.30	0.02	0.17	0.03	0.04	0.03	0.13	0.01	0.29	0.06	8.31	0.99	0.51	0.04
7/4/2006	2.0	PL	0.38	0.02	0.15	0.00	0.12	0.02	b.l.d.	b.l.d.	0.12	0.09	12.77	1.38	0.65	0.03
7/4/2006	6.0	PL	0.32	0.02	0.13	0.00	0.02	0.01	0.09	0.01	0.09	0.06	7.51	1.61	0.46	0.03
7/4/2006	2.0	PL	0.36	0.03	0.16	0.00	0.08	0.00	0.29	0.02	0.17	0.04	10.21	1.47	0.60	0.03
7/4/2006	5.0	PL	0.35	0.02	0.12	0.02	0.08	0.02	0.25	0.01	0.12	0.16	5.97	1.55	0.55	0.04
7/3/2006	2.0	PL	0.34	0.03	0.12	0.01	0.05	0.01	0.24	0.04	0.26	0.39	7.69	0.24	0.51	0.03
7/3/2006	6.0	PL	0.27	0.01	0.15	0.01	0.04	0.02	0.15	0.01	0.23	0.12	5.87	0.98	0.46	0.03
7/3/2006	2.0	PL	0.35	0.04	0.12	0.01	0.02	0.01	b.l.d.	b.l.d.	0.16	0.13	8.81	0.26	0.49	0.04
7/3/2006	10.0	PL	0.29	0.01	0.18	0.03	b.l.d.	b.l.d.	0.12	0.02	0.26	0.22	7.01	1.46	0.48	0.05
7/3/2006	2.0	SS	0.37	0.00	0.15	0.01	0.11	0.04	0.16	0.01	0.10	0.02	4.92	0.71	0.64	0.04
7/3/2006	24.0	SS	0.33	0.03	0.16	0.02	0.15	0.03	0.23	0.02	0.11	0.60	4.99	1.36	0.63	0.05
7/3/2006	2.0	SS	0.38	0.02	0.09	0.02	0.08	0.02	b.l.d.	b.l.d.	0.26	0.07	5.01	0.98	0.54	0.03
7/3/2006	21.0	SS	0.37	0.01	0.12	0.01	0.09	0.02	0.09	0.01	0.14	0.25	5.68	0.90	0.58	0.02
7/4/2006	3.0	SS	0.33	0.03	0.08	0.01	0.10	0.01	b.l.d.	b.l.d.	0.14	0.04	6.19	1.28	0.51	0.03
7/4/2006	31.0	SS	0.35	0.02	0.35	0.01	0.20	0.02	0.09	0.00	0.15	n.d.	5.74	0.52	0.90	0.03
7/4/2006	2.0	SS	0.35	0.01	0.05	0.00	0.16	0.02	0.14	0.01	0.13	n.d.	2.17	0.62	0.56	0.02
7/4/2006	50.7	SS	0.31	0.01	0.21	0.01	1.84	0.15	0.24	0.01	0.22	0.11	3.60	0.96	2.36	0.15

Appendix Table B.1. Continued.

Date	Depth (m)	Region	NH_4^+ (µmol L^{-1})	+/-	NO_2^- (µmol L^{-1})	+/-	NO_3^- (µmol L^{-1})	+/-	Urea N (µmol L^{-1})	+/-	DFAA N (µmol L^{-1})	+/-	DON (µmol L^{-1})	+/-	DIN (µmol L^{-1})	+/-
7/2/2006	2.0	MS	0.39	0.03	0.07	0.00	0.03	0.01	b.l.d.	b.l.d.	0.16	0.04	2.24	0.53	0.49	0.03
7/2/2006	19.9	MS	0.33	0.00	0.13	0.01	0.06	0.02	0.19	0.01	0.11	0.10	1.81	0.57	0.52	0.02
7/2/2006	2.0	MS	0.37	0.02	0.04	0.01	0.07	0.01	b.l.d.	b.l.d.	0.18	0.08	4.26	1.53	0.47	0.03
7/2/2006	19.0	MS	0.33	0.04	0.17	0.01	0.04	0.02	0.19	0.02	0.17	0.12	2.82	1.10	0.54	0.04
7/2/2006	2.0	MS	0.34	0.03	0.08	0.01	0.06	0.02	b.l.d.	b.l.d.	0.18	0.09	8.07	1.96	0.49	0.04
7/2/2006	16.0	MS	0.30	0.03	0.04	0.01	0.12	0.02	b.l.d.	b.l.d.	0.13	0.39	3.34	1.03	0.46	0.03
7/5/2006	2.0	MS	0.36	0.02	0.08	0.00	0.03	0.01	b.l.d.	b.l.d.	0.07	0.03	5.28	0.03	0.47	0.02
7/5/2006	19.0	MS	0.32	0.03	0.20	0.01	b.l.d.	b.l.d.	0.20	0.03	0.13	0.09	5.63	0.59	0.54	0.04
7/5/2006	2.0	MS	0.37	0.03	0.02	0.00	b.l.d.	b.l.d.	b.l.d.	b.l.d.	0.13	0.04	5.94	0.54	0.40	0.03
7/5/2006	23.0	MS	0.30	0.03	0.19	0.01	0.04	0.03	0.17	0.01	0.17	0.09	5.92	1.45	0.53	0.04
7/5/2006	2.0	MS	0.27	0.01	0.17	0.01	0.13	0.01	0.35	0.05	0.09	0.07	6.57	0.75	0.57	0.02
7/5/2006	20.0	MS	0.37	0.03	0.59	0.04	0.83	0.09	0.25	0.02	0.04	0.12	5.93	1.14	1.79	0.10
10/31/2006	2.0	PL	0.73	0.08	0.12	0.03	0.31	0.08	0.17	0.06	0.17	0.03	4.38	0.12	1.15	0.11
10/31/2006	6.0	PL	0.64	0.06	0.09	0.01	0.36	0.06	b.l.d.	b.l.d.	0.18	0.00	16.14	0.23	1.09	0.09
10/31/2006	2.0	PL	1.17	0.07	0.44	0.07	2.58	0.26	0.36	0.02	0.11	0.02	16.07	0.29	4.18	0.28
10/31/2006	6.0	PL	1.70	0.14	0.33	0.06	0.99	0.06	0.32	0.09	0.16	0.03	19.72	0.21	3.02	0.17
10/31/2006	2.0	PL	0.86	0.09	0.49	0.04	1.56	0.49	0.51	0.00	0.22	0.07	17.05	0.53	2.91	0.50
10/31/2006	6.0	PL	1.41	0.08	0.26	0.03	0.95	0.03	0.45	0.13	0.13	0.00	14.73	0.23	2.62	0.09
10/31/2006	2.0	PL	0.45	0.03	0.48	0.06	0.48	0.27	0.36	0.04	0.15	n.d.	13.57	0.59	1.42	0.28
10/31/2006	5.0	PL	0.67	0.07	0.36	0.09	0.33	0.11	0.66	0.04	0.12	0.10	24.90	0.17	1.36	0.15
10/31/2006	2.0	PL	0.21	0.03	0.11	0.01	0.38	0.14	0.40	0.04	0.19	0.04	3.57	0.14	0.70	0.14
10/31/2006	5.0	PL	0.22	0.02	0.13	0.01	0.12	0.01	0.39	0.04	0.31	n.d.	13.27	0.90	0.46	0.02
10/31/2006	2.0	PL	0.40	0.01	0.27	0.05	0.48	0.08	0.40	0.03	0.73	0.07	17.72	n.d.	1.15	0.10
10/31/2006	10.0	PL	0.90	0.09	0.45	0.12	0.24	0.19	0.41	0.06	0.20	0.05	18.33	0.44	1.60	0.24
11/1/2006	2.0	PL	0.72	0.01	0.33	0.02	0.31	0.14	0.25	0.07	0.19	0.06	10.00	0.67	1.36	0.14
11/1/2006	12.0	PL	1.51	0.02	0.65	0.04	0.29	0.07	0.37	0.05	0.42	0.41	10.35	3.99	2.44	0.09
11/1/2006	2.0	SS	0.48	0.02	0.20	0.03	0.08	0.07	0.32	0.03	0.21	0.09	7.03	0.67	0.76	0.08
11/1/2006	10.0	SS	0.38	0.04	0.23	0.03	b.l.d.	b.l.d.	0.83	0.04	0.31	0.08	8.85	0.92	0.62	0.06

Appendix Table B.1. Continued.

Date	Depth (m)	Region	NH_4^+ (μmol L^{-1})	+/-	NO_2^- (μmol L^{-1})	+/-	NO_3^- (μmol L^{-1})	+/-	Urea N (μmol L^{-1})	+/-	DFAA N (μmol L^{-1})	+/-	DON (μmol L^{-1})	+/-	DIN (μmol L^{-1})	+/-
11/1/2006	2.0	SS	0.21	0.03	0.24	0.02	b.l.d.	b.l.d.	0.17	0.04	0.18	0.12	5.91	0.15	0.45	0.04
11/1/2006	17.5	SS	0.63	0.04	0.22	0.00	1.14	0.32	b.l.d.	b.l.d.	0.12	0.01	4.85	0.56	2.00	0.32
11/1/2006	2.0	SS	0.73	0.07	0.12	0.00	b.l.d.	b.l.d.	0.04	0.03	0.15	0.01	7.39	1.19	0.85	0.07
11/1/2006	23.0	SS	0.09	0.01	0.25	0.02	1.50	0.16	0.22	0.04	0.39	0.14	7.02	0.17	1.84	0.16
11/1/2006	2.0	SS	0.07	0.01	0.14	0.02	0.08	0.06	0.24	0.04	0.23	0.01	11.36	0.76	0.28	0.07
11/1/2006	20.0	SS	0.06	0.03	0.12	0.03	0.15	0.07	0.35	0.01	0.26	0.12	7.69	0.35	0.33	0.08
11/1/2006	2.0	SS	0.11	0.02	0.14	0.00	0.16	0.07	0.26	0.03	0.32	0.11	6.82	0.34	0.41	0.07
11/1/2006	10.0	SS	0.03	0.01	0.41	0.00	3.45	0.82	0.22	0.04	0.20	0.03	6.65	1.09	3.88	0.82
11/2/2006	2.0	MS	0.01	0.00	0.11	0.01	b.l.d.	b.l.d.	0.21	0.01	0.25	0.05	10.21	2.68	0.13	0.02
11/2/2006	30.0	MS	b.l.d.	b.l.d.	0.13	n.d.	0.09	n.d.	0.29	0.02	0.16	0.00	7.36	n.d.	0.24	n.d.
11/2/2006	2.0	MS	0.07	0.01	0.12	0.00	0.54	0.09	0.42	0.04	0.21	0.09	7.34	0.39	0.73	0.09
11/2/2006	27.0	MS	0.07	0.01	0.27	0.07	0.53	0.20	0.44	0.02	0.44	0.00	7.37	0.58	0.87	0.21
10/30/2006	2.0	MS	0.86	0.10	0.65	0.07	0.40	0.09	0.27	0.04	0.13	0.01	9.94	0.36	1.91	0.15
10/30/2006	9.0	MS	0.99	0.06	0.61	0.00	0.53	0.09	0.20	0.04	0.18	0.03	10.83	1.07	2.13	0.10

Appendix Table B.2. 2005 – 2006 PO_4^{3-}, SiO_4^{+}, DIC, and alkalinity concentrations for all stations, regions, dates, and depths. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available, b.l.d.= below the limit of detection (NH_4^+: 0.05; NO_2^-: 0.02; NO_3^-: 0.02; Urea: 0.05; DFAA: 0.03).

Date	Depth (m)	Region	PO_4^{3-} (µmol L^{-1})	+/-	SiO_4^{+} (µmol L^{-1})	+/-	DIC	+/-	Alkalinity	+/-
3/30/2005	4.5	PL	0.25	0.01	0.54	0.01	1.86	0.07	2.12	0.01
3/30/2005	18.2	PL	0.28	0.00	0.79	0.09	1.91	0.02	2.12	0.01
3/30/2005	2.0	PL	0.21	0.01	0.55	0.01	1.56	0.01	1.73	0.03
3/30/2005	4.4	PL	0.23	0.02	0.58	0.10	1.72	0.02	1.84	0.01
3/30/2005	5.0	PL	0.18	0.00	0.36	0.22	1.57	0.05	1.82	0.02
3/30/2005	15.0	PL	0.12	0.00	0.75	0.07	1.86	0.03	2.15	0.09
3/30/2005	2.0	PL	0.18	0.00	0.90	0.09	1.62	0.00	1.82	0.01
3/30/2005	13.0	PL	0.12	0.00	0.23	0.14	1.96	0.02	2.13	0.06
3/31/2005	2.0	SS	0.22	0.00	0.90	0.00	2.02	0.02	2.27	0.04
3/31/2005	15.0	SS	0.26	0.01	0.93	0.06	2.00	0.04	2.32	0.04
3/31/2005	5.0	SS	0.47	0.00	1.25	0.27	1.95	0.05	2.10	0.02
3/31/2005	17.0	SS	0.48	0.01	1.31	0.11	1.90	0.00	2.07	0.08
4/1/2005	2.0	MS	0.42	0.01	1.10	0.11	1.94	0.02	2.17	0.00
4/1/2005	53.0	MS	0.51	0.01	1.49	0.06	1.93	0.02	2.21	0.01
4/1/2005	5.0	MS	0.21	0.01	0.72	0.06	1.90	0.01	2.07	0.01
4/1/2005	10.0	MS	0.19	0.00	0.80	0.02	1.86	0.04	2.08	0.00
4/1/2005	2.0	MS	0.29	0.01	0.92	0.02	1.97	0.00	2.12	0.01
4/1/2005	20.8	MS	0.33	0.01	0.99	0.18	1.99	0.01	2.15	0.02
7/26/2005	2.0	PL	0.08	0.01	0.19	0.05	1.82	0.01	2.00	0.00
7/26/2005	12.3	PL	0.32	0.00	0.41	0.01	1.98	0.01	2.12	0.03
7/27/2005	2.0	PL	0.08	0.01	6.46	0.03	1.75	0.00	1.88	0.01
7/27/2005	5.0	PL	0.14	0.00	1.98	0.03	1.81	0.01	1.97	0.01
7/27/2005	2.0	PL	0.16	0.00	3.15	0.00	1.85	0.00	1.99	0.00
7/27/2005	8.0	PL	0.22	0.00	b.l.d.	b.l.d.	1.75	0.04	1.84	0.00
7/27/2005	2.0	PL	0.06	0.00	8.18	0.03	1.75	0.04	1.84	0.00
7/27/2005	15.6	PL	0.50	0.01	0.45	0.05	2.02	0.01	2.07	0.01
7/27/2005	2.0	PL	b.l.d.	b.l.d.	0.20	0.02	1.73	0.01	1.93	0.00
7/27/2005	7.6	PL	0.10	0.00	0.22	0.03	1.91	0.00	2.06	0.00
7/28/2005	2.0	SS	0.02	n.d.	0.99	0.02	1.87	0.00	2.07	0.01

Appendix Table B.2. Continued.

Date	Depth (m)	Region	PO_4^{3-} (µmol L^{-1})	+/-	SiO_4^{+} (µmol L^{-1})	+/-	DIC	+/-	Alkalinity	+/-
7/28/2005	40.0	SS	0.11	0.03	3.11	0.04	1.98	0.01	2.18	0.01
7/29/2005	2.0	MS	0.18	0.01	1.58	0.00	1.91	0.00	2.03	0.01
7/29/2005	7.8	MS	0.21	0.01	0.84	0.01	1.93	0.01	2.05	0.03
7/29/2005	2.0	MS	0.03	0.03	1.48	0.00	1.87	0.00	2.08	0.00
7/29/2005	31.2	MS	0.25	0.01	1.99	0.00	1.99	0.00	2.15	0.00
7/29/2005	2.0	MS	b.l.d.	b.l.d.	0.32	0.02	1.80	0.00	2.00	0.00
7/29/2005	11.0	MS	0.26	0.00	2.34	0.02	1.88	0.00	2.02	0.00
7/30/2005	2.0	MS	b.l.d.	b.l.d.	1.54	0.00	1.82	0.00	2.00	0.01
7/30/2005	23.0	MS	0.41	0.01	4.47	0.02	1.97	0.00	2.07	0.00
5/11/2006	2.0	PL	0.04	0.01	0.79	0.01	1.80	0.36	2.10	0.31
5/11/2006	12.0	PL	0.13	0.01	1.03	0.01	2.49	0.15	2.10	0.02
5/11/2006	1.5	PL	0.07	0.00	1.13	0.03	2.07	0.05	1.97	0.02
5/11/2006	16.0	PL	0.17	0.00	1.33	0.00	2.02	0.07	2.13	0.01
5/11/2006	2.0	PL	0.05	0.01	1.03	0.06	2.33	0.03	1.98	0.02
5/11/2006	14.0	PL	0.17	0.00	1.57	0.00	1.98	0.27	2.10	0.03
5/11/2006	2.0	PL	0.06	0.00	0.99	0.01	1.96	0.01	1.99	0.01
5/11/2006	17.0	PL	0.07	0.00	0.85	0.01	2.15	0.13	2.15	0.01
5/10/2006	1.5	MS	0.06	0.02	1.16	0.12	n.d.	n.d.	n.d.	n.d.
5/10/2006	20.2	MS	0.15	0.01	0.72	n.d.	n.d.	n.d.	n.d.	n.d.
5/10/2006	2.0	MS	0.07	0.01	0.76	0.05	n.d.	n.d.	n.d.	n.d.
5/10/2006	17.7	MS	0.17	0.01	1.08	0.01	n.d.	n.d.	n.d.	n.d.
5/10/2006	1.9	MS	0.16	0.00	0.91	0.00	n.d.	n.d.	n.d.	n.d.
5/10/2006	26.6	MS	0.20	0.00	1.27	0.01	n.d.	n.d.	n.d.	n.d.
5/12/2006	2.0	MS	0.11	0.02	0.90	0.09	n.d.	n.d.	n.d.	n.d.
5/12/2006	23.0	MS	0.09	0.01	0.92	0.07	n.d.	n.d.	n.d.	n.d.
5/12/2006	2.0	MS	0.04	0.01	0.67	0.02	n.d.	n.d.	n.d.	n.d.
5/12/2006	9.0	MS	0.03	0.01	0.80	0.09	n.d.	n.d.	n.d.	n.d.
5/12/2006	2.0	MS	0.15	0.02	0.66	0.06	n.d.	n.d.	n.d.	n.d.
5/12/2006	29.0	MS	0.12	0.02	0.64	0.10	n.d.	n.d.	n.d.	n.d.
5/12/2006	2.0	MS	0.05	0.00	0.82	0.12	n.d.	n.d.	n.d.	n.d.

Appendix Table B.2. Continued.

Date	Depth (m)	Region	PO_4^{3-} (µmol L^{-1})	+/-	SiO_4^{+} (µmol L^{-1})	+/-	DIC	+/-	Alkalinity	+/-
5/12/2006	5.0	MS	0.07	0.01	0.93	0.00	n.d.	n.d.	n.d.	n.d.
5/12/2006	2.0	PL	0.13	0.00	0.79	0.00	n.d.	n.d.	n.d.	n.d.
5/12/2006	5.0	PL	0.14	0.01	1.24	0.00	n.d.	n.d.	n.d.	n.d.
5/12/2006	1.5	PL	0.13	0.01	0.17	0.02	n.d.	n.d.	n.d.	n.d.
5/12/2006	10.0	PL	0.13	0.02	0.46	0.02	n.d.	n.d.	n.d.	n.d.
7/4/2006	2.0	PL	0.06	0.01	7.16	0.84	1.84	0.07	1.94	0.01
7/4/2006	5.5	PL	0.05	0.01	4.93	0.37	1.95	0.13	1.97	0.01
7/4/2006	2.0	PL	0.08	0.01	8.05	0.10	1.86	0.03	1.88	0.01
7/4/2006	6.0	PL	0.21	0.02	4.23	0.23	2.03	0.16	2.03	0.00
7/4/2006	2.0	PL	0.05	0.01	9.25	0.64	1.75	0.01	1.82	0.01
7/4/2006	5.0	PL	0.11	0.00	1.43	0.11	2.07	0.14	2.11	0.00
7/4/2006	2.0	PL	0.05	0.01	10.35	0.22	1.80	0.05	1.85	0.01
7/4/2006	6.0	PL	0.07	0.00	1.23	0.04	2.01	0.06	2.14	0.00
7/4/2006	2.0	PL	0.03	0.01	8.81	0.87	1.85	0.05	1.93	0.00
7/4/2006	10.0	PL	0.11	0.01	1.32	0.14	1.91	0.04	2.10	0.10
7/3/2006	2.0	SS	0.05	0.01	0.15	0.01	n.d.	n.d.	n.d.	n.d.
7/3/2006	24.0	SS	0.15	0.01	0.16	0.02	n.d.	n.d.	n.d.	n.d.
7/3/2006	2.0	SS	0.07	0.01	0.09	n.d.	n.d.	n.d.	n.d.	n.d.
7/3/2006	21.0	SS	0.09	0.01	1.16	0.11	n.d.	n.d.	n.d.	n.d.
7/3/2006	3.0	SS	0.04	0.01	b.l.d.	b.l.d.	n.d.	n.d.	n.d.	n.d.
7/3/2006	31.0	SS	0.10	0.01	0.35	0.01	n.d.	n.d.	n.d.	n.d.
7/3/2006	2.0	SS	0.03	n.d.	0.17	0.04	n.d.	n.d.	n.d.	n.d.
7/3/2006	50.7	SS	0.11	0.02	0.21	0.01	n.d.	n.d.	n.d.	n.d.
7/2/2006	2.0	MS	0.05	0.00	0.21	0.01	n.d.	n.d.	n.d.	n.d.
7/2/2006	19.9	MS	0.08	0.01	1.06	0.07	n.d.	n.d.	n.d.	n.d.
7/2/2006	2.0	MS	0.07	0.00	1.24	0.05	n.d.	n.d.	n.d.	n.d.
7/2/2006	19.0	MS	b.l.d.	b.l.d.	0.86	0.06	n.d.	n.d.	n.d.	n.d.
7/2/2006	2.0	MS	0.21	0.02	2.47	0.07	n.d.	n.d.	n.d.	n.d.
7/2/2006	16.0	MS	0.36	0.04	2.56	0.12	n.d.	n.d.	n.d.	n.d.
7/5/2006	2.0	MS	0.03	0.00	1.52	0.07	n.d.	n.d.	n.d.	n.d.

Appendix Table B.2. Continued.

Date	Depth (m)	Region	PO_4^{3-} (μmol L^{-1})	+/-	SiO_4^{+} (μmol L^{-1})	+/-	DIC	+/-	Alkalinity	+/-
7/5/2006	19.0	MS	0.11	0.00	1.30	0.13	n.d.	n.d.	n.d.	n.d.
7/5/2006	2.0	MS	0.10	0.01	2.00	0.09	n.d.	n.d.	n.d.	n.d.
7/5/2006	23.0	MS	0.22	0.01	1.98	0.12	n.d.	n.d.	n.d.	n.d.
7/5/2006	2.0	MS	0.08	0.01	1.55	0.15	n.d.	n.d.	n.d.	n.d.
7/5/2006	20.0	MS	0.24	0.03	2.50	0.18	n.d.	n.d.	n.d.	n.d.
10/31/2006	2.0	PL	0.23	0.02	3.74	0.08	1.89	0.01	2.08	0.00
10/31/2006	6.0	PL	0.22	0.01	4.09	0.00	1.86	0.07	2.01	0.08
10/31/2006	2.0	PL	0.26	0.02	12.13	0.76	1.71	0.03	1.86	0.00
10/31/2006	6.0	PL	0.27	0.04	8.40	0.53	1.85	0.02	1.98	0.01
10/31/2006	2.0	PL	0.21	0.01	15.04	1.03	1.70	0.02	1.88	0.02
10/31/2006	6.0	PL	0.25	0.02	7.08	0.23	1.77	0.03	2.00	0.01
10/31/2006	2.0	PL	0.19	0.02	6.38	0.23	1.86	0.07	1.98	0.05
10/31/2006	5.0	PL	0.22	0.02	5.06	0.23	1.88	0.06	2.06	0.00
10/31/2006	2.0	PL	0.15	0.02	3.70	0.45	1.83	0.01	2.07	0.01
10/31/2006	5.0	PL	0.15	0.02	3.12	0.15	1.84	0.00	2.09	0.01
10/31/2006	2.0	PL	0.19	0.02	4.40	0.36	1.87	0.02	2.00	0.08
10/31/2006	10.0	PL	0.19	0.00	4.44	0.15	1.85	0.00	2.07	0.02
11/1/2006	2.0	PL	0.19	0.00	4.70	0.21	n.d.	n.d.	n.d.	n.d.
11/1/2006	12.0	PL	0.15	0.01	3.03	0.02	n.d.	n.d.	n.d.	n.d.
11/1/2006	2.0	SS	0.11	0.00	3.17	0.26	n.d.	n.d.	n.d.	n.d.
11/1/2006	10.0	SS	0.11	0.01	1.85	0.17	n.d.	n.d.	n.d.	n.d.
11/1/2006	2.0	SS	0.09	0.01	1.22	0.06	n.d.	n.d.	n.d.	n.d.
11/1/2006	17.5	SS	0.11	0.02	2.00	0.32	n.d.	n.d.	n.d.	n.d.
11/1/2006	2.0	SS	0.10	0.01	0.99	0.04	n.d.	n.d.	n.d.	n.d.
11/1/2006	23.0	SS	0.11	0.02	1.77	0.46	n.d.	n.d.	n.d.	n.d.
11/1/2006	2.0	SS	0.02	0.01	0.31	0.08	n.d.	n.d.	n.d.	n.d.
11/1/2006	20.0	SS	0.03	0.02	0.68	0.05	n.d.	n.d.	n.d.	n.d.
11/1/2006	2.0	SS	0.05	0.00	0.30	0.10	n.d.	n.d.	n.d.	n.d.
11/1/2006	10.0	SS	0.20	0.01	3.16	0.16	n.d.	n.d.	n.d.	n.d.
11/2/2006	2.0	MS	0.04	0.01	0.52	0.07	n.d.	n.d.	n.d.	n.d.

Appendix Table B.2. Continued.

Date	Depth (m)	Region	PO_4^{3-} (µmol L^{-1})	+/-	SiO_4^+ (µmol L^{-1})	+/-	DIC	+/-	Alkalinity	+/-
11/2/2006	30.0	MS	0.06	0.01	0.69	0.03	n.d.	n.d.	n.d.	n.d.
11/2/2006	2.0	MS	0.13	0.00	1.90	0.43	n.d.	n.d.	n.d.	n.d.
11/2/2006	27.0	MS	0.11	0.00	1.29	0.13	n.d.	n.d.	n.d.	n.d.
10/30/2006	2.0	MS	0.22	0.02	6.38	0.26	n.d.	n.d.	n.d.	n.d.
10/30/2006	9.0	MS	0.20	0.02	4.18	0.23	n.d.	n.d.	n.d.	n.d.

Appendix table B.3. 2005 – 2006 Chl *a*, PN, and PC concentrations for all stations, regions, dates, and depths. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available, b.l.d.= below the limit of detection (Chl *a*: 0.002; PN: 0.25; PC: 2.6).

Date	Depth (m)	Lat.	Lon.	Region	Chl *a* (μg chl L^{-1})	+/-	PN (μmol L^{-1})	+/-	PC (μmol L^{-1})	+/-
3/30/2005	4.5	36.91	-75.71	PL	0.78	0.08	2.77	0.02	17.89	0.37
3/30/2005	18.2	36.91	-75.71	PL	0.76	0.07	2.58	0.38	16.01	0.50
3/30/2005	2.0	36.97	-76.02	PL	5.54	0.02	4.62	0.55	30.74	3.00
3/30/2005	4.4	36.97	-76.02	PL	4.68	0.85	5.58	1.83	34.77	10.12
3/30/2005	5.0	36.90	-75.91	PL	12.05	0.42	12.73	0.38	85.21	10.21
3/30/2005	15.0	36.90	-75.91	PL	3.09	0.17	3.96	0.69	28.52	3.84
3/30/2005	2.0	36.80	-75.86	PL	9.08	1.10	9.82	1.31	73.65	20.37
3/30/2005	13.0	36.80	-75.86	PL	3.31	0.00	4.56	0.06	32.40	2.27
3/31/2005	2.0	37.17	-75.71	SS	n.d.	n.d.	3.41	0.71	23.39	5.17
3/31/2005	15.0	37.17	-75.71	SS	n.d.	n.d.	2.61	0.42	17.98	0.92
3/31/2005	5.0	36.68	-74.69	SS	1.12	0.15	1.24	0.03	9.84	0.06
3/31/2005	17.0	36.68	-74.69	SS	0.85	0.01	1.96	0.12	12.07	0.37
4/1/2005	2.0	37.31	-74.71	MS	0.50	0.03	0.96	0.25	8.66	0.80
4/1/2005	53.0	37.31	-74.71	MS	0.43	0.03	1.33	0.03	12.60	0.10
4/1/2005	5.0	37.47	-75.53	MS	0.62	0.03	2.53	0.29	23.49	0.34
4/1/2005	10.0	37.47	-75.53	MS	0.83	0.11	2.47	0.30	23.16	0.80
4/1/2005	2.0	37.78	-75.27	MS	n.d.	n.d.	2.17	0.28	22.32	1.19
4/1/2005	20.8	37.78	-75.27	MS	n.d.	n.d.	3.17	0.22	26.20	2.33
7/26/2005	2.0	36.91	-75.71	PL	0.90	0.00	4.21	0.61	40.59	3.41
7/26/2005	12.3	36.91	-75.71	PL	1.88	0.01	4.66	0.46	33.73	2.39
7/27/2005	2.0	36.97	-76.02	PL	2.23	0.00	4.51	0.11	28.62	0.31
7/27/2005	5.0	36.97	-76.02	PL	1.31	0.04	3.33	0.10	25.05	0.26
7/27/2005	2.0	36.90	-75.90	PL	2.32	0.01	5.38	0.15	38.97	1.66

Appendix Table B.3. Continued.

Date	Depth (m)	Lat.	Lon.	Region	Chl *a* (μg chl L^{-1})	+/-	PN (μmol L^{-1})	+/-	PC (μmol L^{-1})	+/-
7/27/2005	8.0	36.90	-75.90	PL	2.31	0.05	5.26	0.16	44.72	2.83
7/27/2005	2.0	36.80	-75.86	PL	1.29	0.35	5.31	0.00	40.88	0.39
7/27/2005	15.6	36.80	-75.86	PL	6.55	0.28	11.05	0.54	73.33	3.58
7/27/2005	2.0	36.68	-75.77	PL	0.85	0.05	2.78	0.03	35.48	0.62
7/27/2005	7.6	36.68	-75.77	PL	1.04	0.02	4.02	0.43	42.65	0.49
7/28/2005	2.0	36.68	-74.69	SS	0.12	0.04	0.80	0.09	15.06	5.36
7/28/2005	40.0	36.68	-74.69	SS	0.58	0.02	1.85	0.16	14.50	0.18
7/29/2005	2.0	37.48	-75.52	MS	0.82	0.03	3.20	0.25	41.86	1.56
7/29/2005	7.8	37.48	-75.52	MS	0.97	0.02	n.d.	n.d.	n.d.	n.d.
7/29/2005	2.0	37.48	-74.50	MS	0.21	0.00	1.24	0.01	13.97	0.60
7/29/2005	31.2	37.48	-74.50	MS	1.55	0.02	2.46	0.37	17.68	1.01
7/29/2005	2.0	37.80	-75.31	MS	0.79	0.06	3.12	0.16	28.36	0.83
7/29/2005	11.0	37.80	-75.31	MS	1.34	0.04	3.79	0.45	31.82	0.59
7/30/2005	2.0	38.17	-74.60	MS	0.24	0.01	2.48	1.48	16.20	5.35
7/30/2005	23.0	38.17	-74.60	MS	1.67	0.05	3.44	0.13	20.46	0.42
5/11/2006	2.0	36.97	-76.02	PL	3.07	0.10	7.15	0.25	56.79	3.10
5/11/2006	12.0	36.97	-76.02	PL	2.87	0.04	4.88	0.50	46.13	2.67
5/11/2006	1.5	36.90	-75.90	PL	2.95	0.03	5.75	0.48	48.63	2.61
5/11/2006	16.0	36.90	-75.90	PL	2.83	0.24	6.89	0.33	58.20	0.37
5/11/2006	2.0	36.80	-75.86	PL	2.05	0.00	5.11	0.18	46.17	0.74
5/11/2006	14.0	36.80	-75.86	PL	1.84	0.21	4.10	0.00	42.26	0.06
5/11/2006	2.0	36.68	-75.77	PL	1.56	0.04	4.84	0.10	46.79	0.87
5/11/2006	17.0	36.68	-75.77	PL	1.67	0.05	4.17	0.10	43.58	0.43

Appendix Table B.3. Continued.

Date	Depth (m)	Lat.	Lon.	Region	Chl *a* (μg chl L^{-1})	+/-	PN (μmol L^{-1})	+/-	PC (μmol L^{-1})	+/-
5/10/2006	1.5	36.84	-74.60	MS	1.13	0.01	1.89	0.01	15.48	0.21
5/10/2006	20.2	36.84	-74.60	MS	1.23	0.26	2.11	0.08	16.11	0.06
5/10/2006	2.0	36.92	-74.81	MS	1.28	0.03	2.70	0.17	18.24	0.27
5/10/2006	17.7	36.92	-74.81	MS	1.49	0.00	2.18	0.21	16.62	0.21
5/10/2006	1.9	36.95	-75.00	MS	0.74	0.01	1.67	0.01	14.82	0.27
5/10/2006	26.6	36.95	-75.00	MS	1.32	0.02	2.35	0.53	16.62	1.53
5/12/2006	2.0	37.30	-75.21	MS	0.97	0.01	2.31	0.06	24.20	1.49
5/12/2006	23.0	37.30	-75.21	MS	1.05	0.00	2.91	0.05	26.43	0.23
5/12/2006	2.0	37.55	-75.28	MS	1.27	0.01	3.24	0.33	28.49	0.81
5/12/2006	9.0	37.55	-75.28	MS	1.16	0.08	2.96	0.04	29.06	1.56
5/12/2006	2.0	37.70	-75.06	MS	0.66	0.02	2.17	0.08	23.47	0.19
5/12/2006	29.0	37.70	-75.06	MS	0.86	0.00	2.83	0.27	27.00	3.83
5/12/2006	2.0	37.80	-75.31	MS	2.10	0.15	5.25	0.24	38.47	2.21
5/12/2006	5.0	37.80	-75.31	MS	2.35	0.05	5.00	0.13	35.69	0.94
5/9/2006	2.0	38.69	-74.95	PL	3.19	0.01	4.97	0.03	45.34	0.68
5/9/2006	5.0	38.69	-74.95	PL	2.96	0.13	5.68	0.13	53.76	1.18
5/9/2006	1.5	38.88	-75.06	PL	3.56	0.04	5.46	1.28	48.10	4.84
5/9/2006	10.0	38.88	-75.06	PL	8.84	0.24	17.63	1.06	123.15	3.72
7/4/2006	2.0	36.91	-75.71	PL	2.13	0.19	8.97	0.05	58.21	2.06
7/4/2006	5.5	36.91	-75.71	PL	2.05	0.01	7.98	0.25	52.17	1.05
7/4/2006	2.0	36.97	-76.02	PL	3.54	0.07	8.82	0.43	51.16	3.22
7/4/2006	6.0	36.97	-76.02	PL	4.20	0.03	7.32	0.44	41.36	0.46
7/4/2006	2.0	36.90	-75.90	PL	3.98	0.00	9.10	1.27	55.98	3.72
7/4/2006	5.0	36.90	-75.90	PL	3.86	0.12	6.50	0.13	43.04	0.39

Appendix Table B.3. Continued.

Date	Depth (m)	Lat.	Lon.	Region	Chl *a* (μg chl L^{-1})	+/-	PN (μmol L^{-1})	+/-	PC (μmol L^{-1})	+/-
7/4/2006	2.0	36.80	-75.86	PL	2.78	0.34	9.76	0.32	59.45	2.15
7/4/2006	6.0	36.80	-75.86	PL	3.18	0.10	5.65	0.90	44.83	3.63
7/4/2006	2.0	36.68	-75.77	PL	1.88	0.08	7.86	0.12	52.05	0.61
7/4/2006	10.0	36.68	-75.77	PL	1.93	0.18	3.46	0.02	32.66	1.14
7/3/2006	2.0	36.53	-75.27	SS	0.23	0.01	0.92	0.12	11.08	0.19
7/3/2006	24.0	36.53	-75.27	SS	1.35	0.55	4.33	0.38	29.47	0.39
7/3/2006	2.0	36.60	-75.06	SS	0.24	0.04	0.89	0.09	10.88	0.24
7/3/2006	21.0	36.60	-75.06	SS	1.54	0.23	2.29	0.28	19.23	2.14
7/3/2006	3.0	36.62	-74.88	SS	0.22	0.00	0.83	0.02	10.68	0.08
7/3/2006	31.0	36.62	-74.88	SS	2.20	0.21	1.19	0.16	10.81	0.82
7/3/2006	2.0	36.68	-74.69	SS	0.21	n.d.	0.89	0.07	12.30	1.01
7/3/2006	50.7	36.68	-74.69	SS	0.33	0.08	0.61	0.09	9.33	0.00
7/2/2006	2.0	37.52	-75.05	MS	0.24	0.01	1.15	0.01	12.21	0.47
7/2/2006	19.9	37.52	-75.05	MS	1.08	0.09	1.87	0.01	16.07	0.38
7/2/2006	2.0	37.63	-75.15	MS	0.33	0.04	2.32	0.09	27.34	1.25
7/2/2006	19.0	37.63	-75.15	MS	1.92	0.07	5.53	1.47	39.48	3.11
7/2/2006	2.0	37.70	-75.30	MS	0.42	0.05	2.26	0.13	28.11	0.35
7/2/2006	16.0	37.70	-75.30	MS	2.81	0.36	4.10	0.31	34.25	1.60
7/5/2006	2.0	38.04	-74.30	MS	0.20	0.00	1.42	0.02	12.90	0.21
7/5/2006	19.0	38.04	-74.30	MS	0.51	0.05	1.43	0.01	12.01	0.04
7/5/2006	2.0	38.12	-74.39	MS	0.32	0.01	1.39	0.11	12.71	0.11
7/5/2006	23.0	38.12	-74.39	MS	1.33	0.05	1.91	0.03	14.14	0.09
7/5/2006	2.0	38.19	-74.46	MS	0.43	0.05	1.48	0.04	13.52	0.14
7/5/2006	20.0	38.19	-74.46	MS	0.61	0.05	1.16	0.10	11.41	0.05

Appendix Table B.3. Continued.

Date	Depth (m)	Lat.	Lon.	Region	Chl *a* (μg chl L^{-1})	+/-	PN (μmol L^{-1})	+/-	PC (μmol L^{-1})	+/-
10/31/2006	2.0	36.91	-75.71	PL	2.17	0.18	3.80	1.07	23.83	5.31
10/31/2006	6.0	36.91	-75.71	PL	2.49	0.16	3.02	0.07	20.00	0.48
10/31/2006	2.0	36.97	-76.02	PL	3.88	0.71	6.03	0.22	39.19	0.44
10/31/2006	6.0	36.97	-76.02	PL	3.80	0.27	5.06	0.27	35.44	0.11
10/31/2006	2.0	36.90	-75.90	PL	5.88	0.18	6.74	0.19	44.55	0.72
10/31/2006	6.0	36.90	-75.90	PL	3.28	0.35	4.33	0.27	31.25	0.39
10/31/2006	2.0	36.80	-75.86	PL	3.99	0.69	5.22	0.32	35.48	0.06
10/31/2006	5.0	36.80	-75.86	PL	3.80	0.29	4.07	0.00	28.71	2.65
10/31/2006	2.0	36.68	-75.77	PL	3.24	0.36	4.57	0.19	36.22	0.33
10/31/2006	5.0	36.68	-75.77	PL	4.79	0.01	4.61	0.51	35.44	2.65
10/31/2006	2.0	36.43	-75.71	PL	2.96	0.06	3.84	0.34	22.88	0.78
10/31/2006	10.0	36.43	-75.71	PL	2.52	0.39	3.62	0.22	19.94	0.52
11/1/2006	2.0	36.43	-75.69	PL	2.24	0.13	3.25	0.10	16.99	0.34
11/1/2006	12.0	36.43	-75.69	PL	2.21	0.08	2.83	0.45	15.61	2.45
11/1/2006	2.0	36.45	-75.52	SS	2.01	0.04	2.42	0.10	15.34	0.08
11/1/2006	10.0	36.45	-75.52	SS	2.16	0.17	4.68	2.87	22.97	9.76
11/1/2006	2.0	36.45	-75.27	SS	0.91	0.13	2.01	0.27	12.90	0.90
11/1/2006	17.5	36.45	-75.27	SS	1.85	0.10	2.80	0.61	13.54	1.73
11/1/2006	2.0	36.47	-75.06	SS	0.73	0.03	2.36	0.18	14.64	0.35
11/1/2006	23.0	36.47	-75.06	SS	1.67	0.08	2.00	0.07	16.76	7.75
11/1/2006	2.0	36.49	-74.84	SS	0.46	0.04	2.30	0.78	14.62	2.97
11/1/2006	20.0	36.49	-74.84	SS	0.63	0.00	1.79	0.63	10.50	1.73
11/1/2006	2.0	36.68	-74.69	SS	0.93	0.00	2.03	0.13	15.13	0.87
11/1/2006	10.0	36.68	-74.69	SS	0.42	0.05	0.66	0.00	6.94	0.18

Appendix Table B.3. Continued.

Date	Depth (m)	Lat.	Lon.	Region	Chl *a* (µg chl L^{-1})	+/-	PN (µmol L^{-1})	+/-	PC (µmol L^{-1})	+/-
11/2/2006	2.0	37.48	-74.50	MS	0.55	0.02	1.50	0.10	10.13	0.32
11/2/2006	30.0	37.48	-74.50	MS	0.87	0.00	1.18	0.09	8.19	0.33
11/2/2006	2.0	38.04	-74.30	MS	0.64	0.04	2.06	0.21	14.79	0.19
11/2/2006	27.0	38.04	-74.30	MS	1.97	0.00	2.62	0.49	19.04	1.53
10/30/2006	2.0	38.69	-74.95	MS	2.89	0.30	4.86	0.26	36.41	5.55
10/30/2006	9.0	38.69	-74.95	MS	3.81	0.06	5.35	0.01	36.60	0.95

Appendix Table B.4. 2005 – 2006 hourly volumetric, daily volumetric, and Chl *a* normalized daily bicarbonate uptake rates for all stations, regions, dates, and depths. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available.

Date	Depth (m)	Region	HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
3/30/2005	4.5	PL	0.230	0.029	2.761	0.343	3.551	0.159
3/30/2005	18.2	PL	0.206	0.010	2.472	0.118	3.243	0.108
3/30/2005	2.0	PL	0.748	0.043	8.982	0.510	1.622	0.057
3/30/2005	4.4	PL	1.028	0.255	12.336	3.058	2.639	0.307
3/30/2005	5.0	PL	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/30/2005	15.0	PL	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/30/2005	2.0	PL	0.125	0.024	1.499	0.286	0.165	0.226
3/30/2005	13.0	PL	0.042	0.001	0.505	0.015	0.153	0.029
3/31/2005	2.0	SS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/31/2005	15.0	SS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/31/2005	5.0	SS	0.130	0.027	1.564	0.323	1.399	0.246
3/31/2005	17.0	SS	0.116	0.010	1.390	0.120	1.628	0.088
4/1/2005	2.0	MS	0.089	0.024	1.064	0.293	2.122	0.282
4/1/2005	53.0	MS	0.040	0.006	0.484	0.075	1.118	0.172
4/1/2005	5.0	MS	0.100	0.000	1.195	0.003	1.936	0.052
4/1/2005	10.0	MS	0.112	0.016	1.347	0.190	1.628	0.191
4/1/2005	2.0	MS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4/1/2005	20.8	MS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
7/26/2005	2.0	PL	0.579	0.170	6.946	2.042	7.717	0.294
7/26/2005	12.3	PL	0.363	0.028	4.357	0.334	2.313	0.077
7/27/2005	2.0	PL	0.675	0.009	16.191	0.205	7.274	0.013
7/27/2005	5.0	PL	0.550	0.020	13.205	0.473	10.111	0.048
7/27/2005	2.0	PL	1.274	0.162	30.566	3.878	13.204	0.127
7/27/2005	8.0	PL	0.544	0.014	13.046	0.347	5.654	0.035
7/27/2005	2.0	PL	0.871	0.031	20.911	0.746	16.273	0.277
7/27/2005	15.6	PL	1.205	0.067	28.927	1.599	4.416	0.070
7/27/2005	2.0	PL	0.488	0.013	11.722	0.302	13.831	0.060
7/27/2005	7.6	PL	0.286	0.000	6.860	0.007	6.612	0.024
7/28/2005	2.0	SS	0.346	0.029	8.300	0.690	66.601	0.357

Appendix Table B.4. Continued.

Date	Depth (m)	Region	HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
7/28/2005	40.0	SS	0.140	0.202	3.365	4.860	5.814	1.444
7/29/2005	2.0	MS	1.499	0.036	35.981	0.862	43.719	0.041
7/29/2005	7.8	MS	0.769	0.080	18.448	1.918	18.969	0.107
7/29/2005	2.0	MS	0.166	0.010	3.987	0.239	18.653	0.060
7/29/2005	31.2	MS	0.129	0.007	3.095	0.157	2.000	0.052
7/29/2005	2.0	MS	0.638	0.015	15.316	0.359	19.339	0.082
7/29/2005	11.0	MS	0.474	0.015	11.365	0.348	8.513	0.040
7/30/2005	2.0	MS	0.218	0.042	5.235	1.014	22.159	0.201
7/30/2005	23.0	MS	0.276	0.212	6.618	5.088	3.969	0.769
5/11/2006	2.0	PL	1.120	0.025	13.441	0.297	4.378	0.039
5/11/2006	12.0	PL	0.966	0.009	11.588	0.105	4.045	0.015
5/11/2006	1.5	PL	1.229	0.007	14.748	0.078	4.999	0.011
5/11/2006	16.0	PL	0.772	0.022	9.268	0.266	3.275	0.090
5/11/2006	2.0	PL	0.099	0.036	1.192	0.430	0.581	0.361
5/11/2006	14.0	PL	0.162	0.001	1.946	0.007	1.061	0.112
5/11/2006	2.0	PL	0.693	0.003	8.317	0.034	5.332	0.028
5/11/2006	17.0	PL	0.684	0.010	8.213	0.122	4.933	0.033
5/10/2006	1.5	MS	0.073	0.006	0.881	0.066	0.781	0.076
5/10/2006	20.2	MS	0.043	0.001	0.514	0.007	0.418	0.211
5/10/2006	2.0	MS	0.561	0.043	6.735	0.518	5.276	0.080
5/10/2006	17.7	MS	0.546	0.064	6.548	0.764	4.394	0.117
5/10/2006	1.9	MS	0.214	0.005	2.568	0.064	3.471	0.028
5/10/2006	26.6	MS	0.372	0.001	4.461	0.011	3.378	0.017
5/12/2006	2.0	MS	0.278	0.033	3.337	0.401	3.440	0.121
5/12/2006	23.0	MS	0.270	0.027	3.235	0.319	3.074	0.099
5/12/2006	2.0	MS	0.307	0.003	3.683	0.032	2.900	0.010
5/12/2006	9.0	MS	0.295	0.010	3.537	0.124	3.062	0.081
5/12/2006	2.0	MS	0.654	0.001	7.846	0.010	11.842	0.037
5/12/2006	29.0	MS	0.546	0.025	6.554	0.305	7.621	0.047
5/12/2006	2.0	MS	0.151	0.005	1.815	0.066	0.864	0.079

Appendix Table B.4. Continued.

Date	Depth (m)	Region	HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
5/12/2006	5.0	MS	0.289	0.004	3.465	0.045	1.473	0.024
5/9/2006	2.0	PL	0.965	0.024	11.577	0.293	3.629	0.026
5/9/2006	5.0	PL	0.672	0.006	8.067	0.078	2.730	0.046
5/9/2006	1.5	PL	1.357	0.239	16.287	2.867	4.581	0.176
5/9/2006	10.0	PL	1.278	0.051	15.332	0.617	1.734	0.049
7/4/2006	2.0	PL	0.319	0.022	7.663	0.529	3.598	0.114
7/4/2006	5.5	PL	0.244	0.001	5.859	0.017	2.863	0.005
7/4/2006	2.0	PL	0.432	0.055	10.361	1.329	2.929	0.130
7/4/2006	6.0	PL	0.346	0.005	8.303	0.120	1.976	0.016
7/4/2006	2.0	PL	0.376	0.042	9.033	1.007	2.272	0.111
7/4/2006	5.0	PL	0.337	0.000	8.088	0.004	2.094	0.031
7/4/2006	2.0	PL	0.395	0.019	9.486	0.464	3.408	0.133
7/4/2006	6.0	PL	0.223	0.041	5.342	0.986	1.680	0.187
7/4/2006	2.0	PL	0.289	0.008	6.932	0.185	3.694	0.050
7/4/2006	10.0	PL	0.175	0.008	4.207	0.181	2.176	0.102
7/3/2006	2.0	SS	0.092	0.006	2.208	0.147	9.465	0.072
7/3/2006	24.0	SS	0.288	0.001	6.906	0.035	5.125	0.407
7/3/2006	2.0	SS	0.069	0.008	1.661	0.195	6.992	0.190
7/3/2006	21.0	SS	0.152	0.024	3.657	0.581	2.373	0.219
7/3/2006	3.0	SS	0.022	0.001	0.535	0.035	2.403	0.066
7/3/2006	31.0	SS	0.033	0.001	0.782	0.027	0.356	0.103
7/3/2006	2.0	SS	0.046	0.015	1.096	0.349	5.306	n.d.
7/3/2006	50.7	SS	0.098	0.147	2.350	3.534	7.067	1.524
7/2/2006	2.0	MS	0.047	0.003	1.131	0.083	4.646	0.084
7/2/2006	19.9	MS	0.080	0.002	1.915	0.041	1.766	0.083
7/2/2006	2.0	MS	0.160	0.025	3.840	0.600	11.489	0.206
7/2/2006	19.0	MS	0.293	0.022	7.037	0.520	3.670	0.083
7/2/2006	2.0	MS	0.158	0.001	3.795	0.020	9.058	0.120
7/2/2006	16.0	MS	0.280	0.038	6.714	0.904	2.386	0.185
7/5/2006	2.0	MS	0.165	0.001	3.969	0.025	20.091	0.024

Appendix Table B.4. Continued.

Date	Depth (m)	Region	HCO_3^- (μmol L^{-1} h^{-1})	+/-	HCO_3^- (μmol L^{-1} d^{-1})	+/-	HCO_3^- (μmol μg chl^{-1} d^{-1})	+/-
7/5/2006	19.0	MS	0.162	0.005	3.883	0.128	7.572	0.096
7/5/2006	2.0	MS	0.167	0.001	4.020	0.015	12.450	0.025
7/5/2006	23.0	MS	0.239	0.005	5.725	0.115	4.291	0.044
7/5/2006	2.0	MS	0.237	0.001	5.692	0.016	13.237	0.117
7/5/2006	20.0	MS	0.109	0.002	2.622	0.044	4.288	0.081
10/31/2006	2.0	PL	0.191	0.021	4.582	0.508	2.110	0.139
10/31/2006	6.0	PL	0.274	0.017	6.574	0.397	2.640	0.088
10/31/2006	2.0	PL	0.369	0.018	8.856	0.428	2.284	0.190
10/31/2006	6.0	PL	0.289	0.021	6.929	0.508	1.822	0.102
10/31/2006	2.0	PL	0.547	0.021	13.117	0.500	2.233	0.049
10/31/2006	6.0	PL	0.332	0.011	7.966	0.276	2.429	0.111
10/31/2006	2.0	PL	0.413	0.008	9.921	0.184	2.486	0.173
10/31/2006	5.0	PL	0.357	0.011	8.572	0.256	2.254	0.083
10/31/2006	2.0	PL	0.328	0.025	7.861	0.600	2.430	0.135
10/31/2006	5.0	PL	0.315	0.017	7.555	0.403	1.579	0.053
10/31/2006	2.0	PL	0.544	0.034	13.062	0.819	4.420	0.066
10/31/2006	10.0	PL	0.153	0.073	3.668	1.759	1.454	0.504
11/1/2006	2.0	PL	0.235	0.008	5.643	0.190	2.525	0.066
11/1/2006	12.0	PL	0.133	0.007	3.198	0.161	1.450	0.062
11/1/2006	2.0	SS	0.143	0.010	3.432	0.232	1.712	0.070
11/1/2006	10.0	SS	0.211	0.001	5.055	0.019	2.346	0.079
11/1/2006	2.0	SS	0.077	0.010	1.855	0.230	2.039	0.191
11/1/2006	17.5	SS	0.134	0.007	3.205	0.176	1.737	0.076
11/1/2006	2.0	SS	0.065	0.004	1.556	0.091	2.136	0.069
11/1/2006	23.0	SS	0.141	0.001	3.377	0.021	2.018	0.048
11/1/2006	2.0	SS	0.049	0.000	1.184	0.002	2.565	0.077
11/1/2006	20.0	SS	0.063	0.001	1.513	0.023	2.408	0.016
11/1/2006	2.0	SS	0.088	0.007	2.121	0.178	2.272	0.084
11/1/2006	10.0	SS	0.036	0.007	0.862	0.168	2.052	0.225
11/2/2006	2.0	MS	0.147	0.003	3.520	0.069	6.439	0.040

Appendix Table B.4. Continued.

Date	Depth (m)	Region	HCO_3^- (µmol L^{-1} h^{-1})	+/-	HCO_3^- (µmol L^{-1} d^{-1})	+/-	HCO_3^- (µmol chl^{-1} d^{-1})	+/-
11/2/2006	30.0	MS	0.105	0.006	2.521	0.143	2.897	0.057
11/2/2006	2.0	MS	0.007	0.000	0.175	0.000	0.272	0.066
11/2/2006	27.0	MS	0.118	0.155	2.840	3.709	1.441	1.306
10/30/2006	2.0	MS	0.327	0.021	7.856	0.503	2.723	0.123
10/30/2006	9.0	MS	0.327	0.000	7.842	0.000	2.058	0.017

Appendix Table B.5. 2005 – 2006 NH_4^+, NO_2^-, NO_3^-, urea N, and DFAA N volumetric uptake rates for all stations, regions, dates, and depths. Standard deviations (±) are shown next to averages of n = 2. n.d.= no data available.

Date	Depth (m)	Region	NH_4^+ (μmol L^{-1} h^{-1})	+/-	NO_2^- (μmol L^{-1} h^{-1})	+/-	NO_3^- (μmol L^{-1} h^{-1})	+/-	Urea (μmol L^{-1} h^{-1})	+/-	DFAA (μmol L^{-1} h^{-1})	+/-
3/30/2005	4.5	PL	0.172	0.031	0.018	0.001	0.052	0.019	0.090	0.015	0.012	0.002
3/30/2005	18.2	PL	0.051	0.007	0.007	0.001	0.017	0.001	0.024	0.001	0.019	0.005
3/30/2005	2.0	PL	0.065	0.008	0.006	0.002	0.022	0.014	0.040	0.015	0.043	0.003
3/30/2005	4.4	PL	0.091	0.056	0.007	0.002	0.024	0.001	0.026	0.010	0.040	0.009
3/30/2005	5.0	PL	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/30/2005	15.0	PL	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/30/2005	2.0	PL	0.340	0.044	0.003	0.001	0.039	0.021	0.024	0.003	0.110	0.004
3/30/2005	13.0	PL	0.056	0.002	0.002	0.001	0.012	0.010	0.010	0.000	0.115	0.001
3/31/2005	2.0	SS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/31/2005	15.0	SS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3/31/2005	5.0	SS	0.007	0.004	b.l.d.	b.l.d.	0.006	0.000	0.003	0.003	0.004	0.006
3/31/2005	17.0	SS	n.d.	n.d.	b.l.d.	b.l.d.	0.008	0.002	0.004	0.000	b.l.d.	b.l.d.
4/1/2005	2.0	MS	0.078	0.019	b.l.d.	b.l.d.	0.002	0.001	b.l.d.	b.l.d.	0.002	0.001
4/1/2005	53.0	MS	0.113	0.015	b.l.d.	b.l.d.	0.001	0.000	0.002	0.000	0.002	0.000
4/1/2005	5.0	MS	0.007	0.000	0.001	0.000	0.029	0.001	0.004	0.000	0.025	0.002
4/1/2005	10.0	MS	0.010	0.002	0.001	0.000	0.028	0.000	0.010	0.002	0.015	0.000
4/1/2005	2.0	MS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4/1/2005	20.8	MS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
7/26/2005	2.0	PL	0.305	0.070	0.024	0.001	0.088	0.010	0.067	0.009	0.042	0.006
7/26/2005	12.3	PL	0.225	0.025	0.030	0.000	0.046	0.001	0.046	0.000	0.012	0.001
7/27/2005	2.0	PL	0.353	0.027	0.059	0.001	0.038	0.018	0.056	0.008	0.032	0.001
7/27/2005	5.0	PL	0.215	0.010	0.012	0.000	0.019	0.001	0.021	0.002	0.011	0.004
7/27/2005	2.0	PL	0.280	0.015	0.055	0.003	0.190	0.008	0.040	0.000	0.034	0.005
7/27/2005	8.0	PL	0.233	0.022	0.044	0.001	0.101	0.006	0.049	0.003	0.018	0.000
7/27/2005	2.0	PL	0.325	0.016	0.031	0.001	0.143	0.006	0.079	0.018	0.049	0.000
7/27/2005	15.6	PL	0.329	0.017	0.021	0.003	0.089	0.009	0.044	0.011	0.028	0.001
7/27/2005	2.0	PL	0.168	0.008	0.019	0.000	0.078	0.004	0.024	0.007	0.021	0.000
7/27/2005	7.6	PL	0.151	0.006	0.013	0.001	0.054	0.006	0.023	0.000	0.025	0.002
7/28/2005	2.0	SS	0.125	0.007	0.007	0.001	0.027	0.003	0.014	0.001	0.003	0.000

Appendix Table B.5. Continued.

Date	Depth (m)	Region	NH_4^+ (μmol L^{-1} h^{-1})	+/-	NO_2^- (μmol L^{-1} h^{-1})	+/-	NO_3^- (μmol L^{-1} h^{-1})	+/-	Urea (μmol L^{-1} h^{-1})	+/-	DFAA (μmol L^{-1} h^{-1})	+/-
7/28/2005	40.0	SS	0.134	0.000	0.010	0.003	0.017	0.000	0.062	0.003	0.002	0.000
7/29/2005	2.0	MS	0.140	0.004	0.020	0.001	0.078	0.005	0.248	0.014	0.059	0.005
7/29/2005	7.8	MS	0.244	0.047	0.015	0.000	0.056	0.009	0.025	0.001	0.010	0.001
7/29/2005	2.0	MS	0.096	0.000	0.004	0.000	0.011	0.000	0.010	0.001	0.003	0.000
7/29/2005	31.2	MS	0.075	0.006	0.003	0.000	0.011	0.003	0.009	0.001	0.003	0.000
7/29/2005	2.0	MS	0.316	0.003	0.017	0.000	0.053	0.005	0.028	0.001	0.016	0.001
7/29/2005	11.0	MS	0.234	0.032	0.018	0.002	0.029	0.001	0.020	0.003	b.l.d.	b.l.d.
7/30/2005	2.0	MS	0.030	0.014	0.007	0.002	0.009	0.008	0.037	0.021	0.008	0.005
7/30/2005	23.0	MS	0.030	0.004	0.001	0.000	0.002	0.000	0.004	0.000	0.002	0.000
5/11/2006	2.0	PL	0.085	0.004	0.037	0.002	0.030	0.000	0.023	0.000	0.032	0.006
5/11/2006	12.0	PL	0.065	0.004	0.024	0.002	0.021	0.002	0.020	0.001	0.013	0.001
5/11/2006	1.5	PL	0.087	0.010	0.045	0.006	0.019	0.002	0.114	0.018	0.047	0.005
5/11/2006	16.0	PL	0.082	0.003	0.036	0.001	0.018	0.000	0.144	0.011	0.026	0.001
5/11/2006	2.0	PL	0.076	0.003	0.015	0.001	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.
5/11/2006	14.0	PL	0.055	0.000	0.006	0.000	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.
5/11/2006	2.0	PL	0.016	0.001	0.039	0.006	0.016	0.001	0.035	0.000	0.068	0.004
5/11/2006	17.0	PL	0.018	0.001	0.035	0.002	0.017	0.003	0.050	0.001	0.052	0.001
5/10/2006	1.5	MS	0.039	0.002	0.004	0.000	0.007	0.000	0.013	0.000	0.002	0.000
5/10/2006	20.2	MS	0.040	0.000	0.008	0.001	0.006	0.000	0.014	0.001	0.002	0.000
5/10/2006	2.0	MS	0.053	0.005	0.018	0.004	0.009	0.007	0.019	0.001	0.004	0.000
5/10/2006	17.7	MS	0.035	0.006	0.003	0.000	0.019	0.001	0.015	0.002	0.002	0.000
5/10/2006	1.9	MS	0.044	0.002	0.009	0.001	0.009	0.001	0.019	0.000	0.003	0.001
5/10/2006	26.6	MS	0.054	0.016	0.012	0.001	0.012	0.002	0.028	0.007	0.003	0.000
5/12/2006	2.0	MS	0.006	0.000	0.018	0.001	0.019	0.001	0.040	0.004	0.034	0.004
5/12/2006	23.0	MS	0.048	0.003	0.011	0.001	0.019	0.001	0.018	0.002	0.004	0.000
5/12/2006	2.0	MS	0.058	0.007	0.023	0.004	0.029	0.000	0.047	0.008	0.006	0.000
5/12/2006	9.0	MS	0.049	0.002	0.021	0.002	0.022	0.000	0.031	0.002	0.005	0.000
5/12/2006	2.0	MS	0.057	0.000	0.024	0.003	0.009	0.000	0.033	0.003	0.003	0.000
5/12/2006	29.0	MS	0.040	0.001	0.015	0.000	0.010	0.001	0.020	0.003	0.005	0.000
5/12/2006	2.0	MS	0.054	0.023	0.014	0.001	0.022	0.000	0.037	0.002	0.010	0.001

Appendix Table B.5. Continued.

Date	Depth (m)	Region	NH_4^+ (μmol L^{-1} h^{-1})	+/-	NO_2^- (μmol L^{-1} h^{-1})	+/-	NO_3^- (μmol L^{-1} h^{-1})	+/-	Urea (μmol L^{-1} h^{-1})	+/-	DFAA (μmol L^{-1} h^{-1})	+/-
5/12/2006	5.0	MS	0.066	0.005	0.025	0.002	0.012	0.000	0.063	0.002	0.012	0.001
5/12/2006	2.0	PL	0.061	0.011	0.023	0.002	0.015	0.000	0.029	0.005	0.005	0.006
5/12/2006	5.0	PL	0.048	0.006	0.014	0.001	0.011	0.001	0.024	0.000	0.008	0.000
5/12/2006	1.5	PL	0.072	0.016	0.023	0.010	0.014	0.001	0.024	0.009	0.013	0.003
5/12/2006	10.0	PL	0.068	0.001	0.023	0.006	0.013	0.000	0.024	0.001	0.026	0.002
7/4/2006	2.0	PL	0.125	0.003	0.056	0.000	0.046	0.000	0.041	0.003	0.036	0.001
7/4/2006	5.5	PL	0.111	0.006	0.073	0.001	0.034	0.001	0.036	0.001	0.063	0.002
7/4/2006	2.0	PL	0.100	0.004	0.045	0.003	0.033	0.000	0.009	0.000	0.013	0.000
7/4/2006	6.0	PL	0.080	0.005	0.029	0.001	0.013	0.001	0.013	0.000	0.006	0.000
7/4/2006	2.0	PL	0.094	0.008	0.054	0.013	0.038	0.006	0.047	0.005	0.040	0.006
7/4/2006	5.0	PL	0.085	0.003	0.028	0.000	0.025	0.003	0.032	0.000	0.012	0.000
7/4/2006	2.0	PL	0.081	0.002	0.045	0.001	0.029	0.001	0.036	0.000	0.051	0.002
7/4/2006	6.0	PL	0.051	0.003	0.038	0.004	0.021	0.003	0.027	0.003	0.016	0.002
7/4/2006	2.0	PL	0.107	0.002	0.055	0.001	0.027	0.002	0.020	0.001	0.041	0.001
7/4/2006	10.0	PL	0.068	0.004	0.036	0.001	0.013	0.002	0.023	0.000	0.010	0.001
7/3/2006	2.0	SS	0.049	0.000	0.013	0.000	0.008	0.002	0.012	0.001	0.005	0.000
7/3/2006	24.0	SS	0.079	0.000	0.014	0.001	0.016	0.002	0.036	0.003	0.006	0.002
7/3/2006	2.0	SS	0.073	0.002	0.017	0.001	0.013	0.001	0.010	0.001	0.006	0.000
7/3/2006	21.0	SS	0.051	0.002	0.009	0.001	0.007	0.001	0.014	0.001	0.004	0.000
7/3/2006	3.0	SS	0.053	0.009	0.014	0.004	0.018	0.000	0.009	0.001	0.002	0.002
7/3/2006	31.0	SS	0.027	0.003	0.004	0.001	0.003	0.000	0.005	0.000	0.002	0.000
7/3/2006	2.0	SS	0.050	0.004	0.010	0.001	0.018	0.005	0.011	0.002	0.002	0.000
7/3/2006	50.7	SS	0.016	0.002	0.001	0.000	0.013	0.002	0.005	0.001	0.001	0.000
7/2/2006	2.0	MS	0.131	0.004	0.032	0.002	0.019	0.004	0.020	0.000	0.012	0.000
7/2/2006	19.9	MS	0.092	0.023	0.029	0.009	0.018	0.002	0.038	0.002	0.006	0.000
7/2/2006	2.0	MS	0.129	0.009	0.014	0.001	0.024	0.005	0.013	0.003	0.011	0.000
7/2/2006	19.0	MS	0.079	0.028	0.031	0.005	0.016	0.001	0.032	0.012	0.006	0.001
7/2/2006	2.0	MS	0.075	0.006	0.014	0.001	0.014	0.001	0.010	0.001	0.007	0.000
7/2/2006	16.0	MS	0.059	0.002	0.021	0.002	0.030	0.002	0.013	0.001	0.004	0.000
7/5/2006	2.0	MS	0.076	0.001	0.022	0.003	0.015	0.002	0.014	0.001	0.005	0.000

Appendix Table B.5. Continued.

Date	Depth (m)	Region	NH_4^+ (µmol L^{-1} h^{-1})	+/-	NO_2^- (µmol L^{-1} h^{-1})	+/-	NO_3^- (µmol L^{-1} h^{-1})	+/-	Urea (µmol L^{-1} h^{-1})	+/-	DFAA (µmol L^{-1} h^{-1})	+/-
7/5/2006	19.0	MS	0.030	0.001	0.002	0.000	0.001	0.000	0.008	0.002	0.002	0.000
7/5/2006	2.0	MS	0.056	0.000	0.010	0.002	0.009	0.000	0.008	0.002	0.005	0.000
7/5/2006	23.0	MS	0.023	0.001	0.007	0.002	0.004	0.000	0.012	0.003	0.003	0.000
7/5/2006	2.0	MS	0.047	0.006	0.028	0.005	0.024	0.001	0.029	0.002	0.005	0.000
7/5/2006	20.0	MS	0.011	0.001	0.002	0.000	0.003	0.000	0.002	0.000	0.001	0.000
10/31/2006	2.0	PL	0.025	0.002	0.001	0.000	0.004	0.001	0.003	0.000	0.003	0.000
10/31/2006	6.0	PL	0.022	0.011	0.003	0.000	0.007	0.000	0.002	0.000	0.004	0.000
10/31/2006	2.0	PL	0.071	0.003	0.002	0.000	0.009	0.000	0.015	0.001	0.005	0.000
10/31/2006	6.0	PL	0.048	0.002	0.001	0.000	0.003	0.000	0.009	0.001	0.005	0.000
10/31/2006	2.0	PL	0.133	0.001	0.009	0.000	0.028	0.000	0.035	0.006	0.009	0.000
10/31/2006	6.0	PL	0.050	0.002	0.001	0.000	0.004	0.000	0.008	0.002	0.004	0.000
10/31/2006	2.0	PL	0.062	0.001	0.009	0.001	0.010	0.000	0.013	0.001	0.004	0.000
10/31/2006	5.0	PL	0.050	0.000	0.005	0.000	0.004	0.000	0.011	0.002	0.002	0.000
10/31/2006	2.0	PL	0.031	0.001	0.011	0.000	0.023	0.000	0.014	0.002	0.003	0.000
10/31/2006	5.0	PL	0.029	0.002	0.011	0.000	0.011	0.001	0.021	0.011	0.003	0.001
10/31/2006	2.0	PL	0.012	0.001	0.002	0.001	0.003	0.000	0.004	0.000	0.005	0.000
10/31/2006	10.0	PL	0.011	0.000	0.001	0.000	b.l.d.	b.l.d.	0.002	0.000	0.002	0.000
11/1/2006	2.0	PL	0.040	0.001	0.008	0.000	0.008	0.000	0.005	0.001	0.002	0.000
11/1/2006	12.0	PL	0.025	0.002	0.003	0.001	0.002	0.000	0.002	0.000	0.003	0.000
11/1/2006	2.0	SS	0.048	0.002	0.011	0.004	0.008	0.001	0.011	0.000	0.002	0.000
11/1/2006	10.0	SS	0.045	0.002	0.018	0.001	0.006	0.000	0.034	0.001	0.005	0.001
11/1/2006	2.0	SS	0.024	0.002	0.014	0.002	0.004	0.000	0.010	0.000	0.002	0.000
11/1/2006	17.5	SS	0.025	0.000	0.005	0.001	0.018	0.001	0.002	0.000	0.002	0.000
11/1/2006	2.0	SS	0.078	0.012	0.011	0.001	0.005	0.001	0.006	0.001	0.002	0.000
11/1/2006	23.0	SS	0.005	0.001	0.002	0.000	0.011	0.003	0.004	0.000	0.003	0.001
11/1/2006	2.0	SS	0.016	0.002	0.013	0.002	0.010	0.000	0.022	0.001	0.005	0.000
11/1/2006	20.0	SS	0.010	0.002	0.005	0.001	0.007	0.000	0.016	0.002	0.002	0.001
11/1/2006	2.0	SS	0.023	0.002	0.013	0.001	0.013	0.000	0.015	0.001	0.006	0.000
11/1/2006	10.0	SS	0.001	0.000	0.001	0.000	0.003	0.000	0.001	0.000	0.001	0.000
11/2/2006	2.0	MS	0.009	0.000	0.007	0.002	0.004	0.000	0.011	0.001	0.004	0.000

Appendix Table B.5. Continued.

Date	Depth (m)	Region	NH_4^+ (µmol L^{-1} h^{-1})	+/-	NO_2^- (µmol L^{-1} h^{-1})	+/-	NO_3^- (µmol L^{-1} h^{-1})	+/-	Urea (µmol L^{-1} h^{-1})	+/-	DFAA (µmol L^{-1} h^{-1})	+/-
11/2/2006	30.0	MS	0.003	0.000	0.002	0.000	0.002	0.000	0.003	0.000	0.002	0.000
11/2/2006	2.0	MS	0.020	0.000	0.012	0.002	0.036	0.008	0.019	0.000	0.003	0.001
11/2/2006	27.0	MS	0.011	0.004	0.015	0.000	0.024	0.003	0.018	0.000	0.041	0.045
10/30/2006	2.0	MS	0.023	0.002	0.001	0.000	0.001	0.000	0.004	0.000	0.004	0.001
10/30/2006	9.0	MS	0.007	0.000	0.288	0.406	0.001	0.000	0.001	0.000	0.005	0.002

Appendix Table B.6. Euphotic depths from radiometry measurements, K490 algorithms from both SeaWifs and MODIS sensors, and shipboard 1% PAR measurements, at each station for each cruise. The total depth of the water column and the fluorescence maximum is given, followed by the final euphotic depth used for areal rate calculations. Superscripts denote which method was used to determine the euphotic depth:

[1] If no modeled or measured estimates were available, and the fluorescence maximum was equal to the depth of the water column, the depth of the water columns was used as the euphotic depth.

[2] 1% PAR was used as the euphotic depth, as no other modeled or measured estimates were available.

[3] Modeled or measured estimates were greater than the water column depth, therefore the depth of the water column was used as the euphotic depth.

[4] Radiometry and/or K490 measurements did not agree, therefore used 1% PAR measurement as euphotic depth.

[5] Only had radiometry or K490 measurements available, and they were not greater than the water column depth, therefore either radiometry or K490 measurements were used as the euphotic depth.

[6] If no PAR, radiometry, or K490 measurements were available, then used the base of the fluorescence maximum as the euphotic depth if it was shallower than the depth of the water column.

				Euphotic depth						
				Method of measurement						
Date	Latitiude	Longitude	Region	Radiometer (m)	K490 (SeaWifs) (m)	K490 (MODIS) (m)	1% PAR (m)	Depth of water column (m)	Fluorescence maximum (m)	Euphotic depth used (m)
3/30/2005	36.91	-75.71	PL	n.d.	n.d.	n.d.	n.d.	19.0	19.0	19.0^{1}
3/30/2005	36.97	-76.02	PL	n.d.	n.d.	n.d.	n.d.	14.0	5.0	5.0^{6}
3/30/2005	36.90	-75.91	PL	n.d.	n.d.	n.d.	7.0	14.0	5.0	7.0^{2}
3/30/2005	36.80	-75.86	PL	n.d.	n.d.	n.d.	8.2	13.0	6.0	8.2^{2}
3/31/2005	36.68	-74.69	SS	n.d.	n.d.	n.d.	n.d.	200.0	128.0	128.0^{6}
4/1/2005	37.31	-74.71	MS	n.d.	n.d.	n.d.	n.d.	61.0	61.0	61.0^{1}
4/1/2005	37.47	-75.53	MS	26.4	n.d.	n.d.	n.d.	16.0	16.0	16.0^{3}
4/1/2005	37.78	-75.27	MS	28.6	n.d.	n.d.	n.d.	21.0	21.0	21.0^{3}
7/26/2005	36.91	-75.71	PL	n.d.	n.d.	n.d.	17.2	10.4	10.4	10.4^{3}
7/27/2005	36.97	-76.02	PL	12.8	21.5	n.d.	5.4	13.5	13.5	13.5^{3}
7/27/2005	36.90	-75.90	PL	14.7	19.7	n.d.	13.0	17.0	17.0	13.0^{4}
7/27/2005	36.81	-75.86	PL	17.2	16.2	n.d.	13.8	16.0	16.0	13.8^{4}
7/27/2005	36.68	-75.77	PL	25.0	31.0	30.7	17.2	19.0	19.0	17.2^{4}
7/28/2005	36.68	-74.69	SS	73.3	n.d.	n.d.	26.6	80.0	35.5	26.6^{4}

Appendix Table B.6. Continued.

				Euphotic depth						
				Method of measurement						
Date	Latitiude	Longitude	Region	Radiometer (m)	K490 (SeaWifs) (m)	K490 (MODIS) (m)	1% PAR (m)	Depth of water column (m)	Fluorescence maximum (m)	Euphotic depth used (m)
7/29/2005	37.48	-75.52	MS	n.d.	n.d.	n.d.	16.4	14.0	14.0	14.0[3]
7/29/2005	37.50	-74.50	MS	55.1	n.d.	n.d.	28.7	100.0	34.5	28.7[4]
7/29/2005	37.80	-75.31	MS	51.4	n.d.	n.d.	15.6	11.5	11.5	11.5[3]
7/30/2005	38.17	-74.60	MS	30.5	n.d.	n.d.	32.4	43.5	23.0	32.4[4]
5/11/2006	36.97	-76.02	PL	n.d.	13.4	n.d.	n.d.	12.0	12.0	12.0[3]
5/11/2006	36.90	-75.90	PL	n.d.	15.1	n.d.	n.d.	16.0	16.0	16.0[3]
5/11/2006	36.80	-75.86	PL	n.d.	18.5	18.8	n.d.	14.0	6.0	14.0[3]
5/11/2006	36.68	-75.77	PL	n.d.	21.4	22.2	n.d.	17.0	17.0	17.0[3]
5/10/2006	36.84	-74.60	MS	n.d.	38.3	35.4	n.d.	500.0	16.0	36.8[5]
5/10/2006	36.92	-74.81	MS	n.d.	39.2	35.3	n.d.	53.0	18.0	37.2[5]
5/10/2006	36.95	-75.00	MS	n.d.	40.4	38.8	n.d.	38.0	26.0	38.0[3]
5/12/2006	37.30	-75.21	MS	n.d.	31.3	30.2	n.d.	24.0	24.0	24.0[3]
5/12/2006	37.78	-75.27	MS	n.d.	26.2	26.7	n.d.	9.0	9.0	9.0[3]
5/12/2006	37.70	-75.06	MS	n.d.	33.5	33.2	n.d.	30.0	25.0	30.0[3]
5/12/2006	37.80	-75.31	MS	n.d.	21.9	22.1	7.6	11.0	11.0	7.6[4]
5/9/2006	38.69	-74.95	PL	n.d.	n.d.	n.d.	n.d.	11.0	11.0	11.0[1]
5/9/2006	38.88	-75.06	PL	n.d.	n.d.	n.d.	n.d.	15.0	15.0	15.0[1]
7/4/2006	36.91	-75.71	PL	11.7	n.d.	n.d.	n.d.	18.0	5.0	11.7[5]
7/4/2006	36.97	-76.02	PL	n.d.	n.d.	n.d.	n.d.	13.0	5.0	5.0[6]
7/4/2006	36.90	-75.90	PL	n.d.	n.d.	n.d.	n.d.	15.0	5.0	5.0[6]
7/4/2006	36.80	-75.86	PL	11.8	n.d.	n.d.	n.d.	14.0	6.0	11.8[5]
7/4/2006	36.68	-75.77	PL	13.0	n.d.	n.d.	n.d.	18.0	13.0	13.0[5]

Appendix Table B.6. Continued.

				Euphotic depth						
				Method of measurement						
Date	Latitiude	Longitude	Region	Radiometer (m)	K490 (SeaWifs) (m)	K490 (MODIS) (m)	1% PAR (m)	Depth of water column (m)	Fluorescence maximum (m)	Euphotic depth used (m)
7/3/2006	36.53	-75.27	SS	n.d.	n.d.	n.d.	n.d.	36.0	25.0	25.0[6]
7/3/2006	36.60	-75.06	SS	66.0	n.d.	n.d.	n.d.	25.0	25.0	25.0[1]
7/3/2006	36.62	-74.88	SS	76.5	67.7	n.d.	n.d.	42.0	42.0	42.0[1]
7/3/2006	36.68	-74.69	SS	n.d.	n.d.	n.d.	n.d.	100.0	53.0	53.0[6]
7/2/2006	37.52	-75.05	MS	57.0	50.8	n.d.	n.d.	29.0	27.0	29.0[1]
7/2/2006	37.63	-75.15	MS	52.4	50.2	n.d.	n.d.	24.0	20.0	24.0[1]
7/2/2006	37.70	-75.30	MS	33.4	42.2	n.d.	n.d.	21.0	16.0	21.0[1]
7/5/2006	38.04	-74.30	MS	n.d.	n.d.	n.d.	n.d.	48.0	31.0	31.0[6]
7/5/2006	38.12	-74.39	MS	44.2	n.d.	n.d.	n.d.	40.0	24.0	40.0[1]
7/5/2006	38.19	-74.46	MS	39.4	n.d.	n.d.	n.d.	40.0	30.0	40.0[1]
10/31/2006	36.91	-75.71	PL	n.d.	n.d.	n.d.	n.d.	14.0	14.0	14.0[1]
10/31/2006	36.97	-76.02	PL	n.d.	n.d.	n.d.	8.4	13.0	13.0	8.4[2]
10/31/2006	36.90	-75.90	PL	n.d.	n.d.	n.d.	8.9	16.0	3.0	8.9[2]
10/31/2006	36.80	-75.86	PL	n.d.	n.d.	n.d.	10.8	15.0	15.0	10.8[2]
10/31/2006	36.68	-75.77	PL	n.d.	n.d.	n.d.	14.9	19.0	19.0	14.9[2]
10/31/2006	36.43	-75.71	PL	n.d.	n.d.	n.d.	10.8	19.0	19.0	10.8[2]
11/1/2006	36.43	-75.69	PL	n.d.	n.d.	n.d.	n.d.	20.0	20.0	20.0[1]
11/1/2006	36.45	-75.52	SS	n.d.	n.d.	n.d.	11.7	25.0	25.0	11.7[2]
11/1/2006	36.53	-75.27	SS	n.d.	n.d.	n.d.	10.9	34.0	17.0	10.9[2]
11/1/2006	36.60	-75.06	SS	n.d.	n.d.	n.d.	33.0	36.0	23.0	33.0[2]
11/1/2006	36.62	-74.88	SS	n.d.	n.d.	n.d.	34.8	39.0	39.0	34.8[2]

Appendix table B.6. Continued.

				Euphotic depth						
					Method of measurement					
Date	Latitiude	Longitude	Region	Radiometer (m)	K490 (SeaWifs) (m)	K490 (MODIS) (m)	1% PAR (m)	Depth of water column (m)	Fluorescence maximum (m)	Euphotic depth used (m)
11/1/2006	36.68	-74.69	SS	n.d.	n.d.	n.d.	26.8	350.0	28.0	26.8^{2}
11/2/2006	37.50	-74.50	MS	n.d.	n.d.	n.d.	n.d.	400.0	35.0	35.0^{6}
11/2/2006	38.04	-74.30	MS	n.d.	n.d.	n.d.	31.3	67.0	27.0	31.3^{2}
10/30/2006	38.69	-74.95	MS	n.d.	n.d.	n.d.	n.d.	13.0	15.0	15.0^{6}

Appendix table B.7. Pearson's product moment correlation for all parameters in the MAB. R = regression coefficient, $p < 0.05$ is significant, and n = sample number.

		S	Chl *a*	PN	PC	DIC	Alkalinity	NH$_4^+$	NO$_2^-$	NO$_3^-$	Urea	DFAA N	DIN	DON	TDN	PO$_4^{3-}$	SiO$_4^+$
			(μg chl L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(mmol L^{-1})		(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})	(μmol L^{-1})
T	R	-0.113	-0.232	-0.0876	-0.0628	-0.169	-0.336	-0.238	0.173	-0.135	-0.0572	-0.184	-0.172	-0.0664	-0.0908	-0.543	0.197
(oC)	p	0.28	0.0279	0.404	0.55	0.206	0.01	0.0211	0.0953	0.194	0.584	0.0766	0.097	0.525	0.384	1.57E-08	0.0575
	n	94	90	93	93	58	58	94	94	94	94	94	94	94	94	94	94
S	R		-0.513	-0.541	-0.553	0.456	0.624	-0.359	-0.0344	0.0406	-0.0292	-0.257	-0.126	-0.466	-0.478	0.0178	-0.439
	p		0.000000229	2.17E-08	9.02E-09	0.00032	1.68E-07	0.00038	0.742	0.698	0.78	0.0125	0.227	0.00000223	0.00000109	0.865	9.83E-06
	n		90	93	93	58	58	94	94	94	94	94	94	94	94	94	94
Chl *a*	R			0.824	0.761	-0.33	-0.467	0.178	0.162	-0.0479	0.289	0.384	0.0611	0.0867	0.0993	0.203	0.261
(μg chl L^{-1})	p			1.29E-30	9.32E-24	0.00771	0.0000993	0.0519	0.0778	0.603	0.00135	0.0000148	0.507	0.338	0.28	0.0263	0.00402
	n			119	119	64	64	120	120	120	120	120	120	124	120	120	120
PN	R				0.952	-0.209	-0.55	0.0464	0.0155	-0.191	0.103	0.203	-0.116	0.145	0.126	0.021	0.348
(μmol L^{-1})	p				4.13E-64	0.0899	0.00000141	0.611	0.865	0.0347	0.259	0.0241	0.2	0.109	0.166	0.818	0.0000811
	n				123	67	67	123	123	123	123	123	123	123	123	123	123
PC	R					-0.0984	-0.486	0.0106	-0.0741	-0.234	0.0655	0.227	-0.176	0.197	0.168	-0.0301	0.219
(μmol L^{-1})	p					0.428	0.000031	0.908	0.415	0.00914	0.472	0.0115	0.052	0.0288	0.0628	0.741	0.0149
	n					67	67	123	123	123	123	123	123	123	123	123	123
DIC	R						0.614	-0.233	-0.185	-0.147	-0.312	-0.245	-0.212	-0.146	-0.174	0.04	-0.296
(mmol L^{-1})	p						2.53E-08	0.0553	0.131	0.233	0.00954	0.0442	0.0826	0.236	0.155	0.746	0.0142
	n						68	68	68	68	68	68	68	68	68	68	68
Alkalinity	R							0.12	-0.261	0.0649	-0.188	-0.171	0.059	0.00158	0.011	0.27	-0.454
	p							0.328	0.0315	0.599	0.125	0.164	0.633	0.99	0.929	0.0259	0.000101
	n							68	68	68	68	68	68	68	68	68	68
NH$_4^+$	R								0.0892	0.373	0.121	0.201	0.695	0.404	0.483	0.606	0.225
(μmol L^{-1})	p								0.324	0.0000198	0.18	0.0254	3.22E-19	0.0000032	1.39E-08	8.62E-14	0.012
	n								124	124	124	124	124	124	124	124	124
NO$_2^-$	R									0.265	0.253	-0.116	0.378	-0.0874	-0.0357	0.0958	0.424
(μmol L^{-1})	p									0.00297	0.00462	0.199	0.0000151	0.335	0.693	0.29	9.3E-07
	n									124	124	124	124	124	124	124	124
NO$_3^-$	R										0.1	0.057	0.912	0.0159	0.134	0.5	0.214
(μmol L^{-1})	p										0.267	0.529	3.79E-49	0.861	0.138	3.39E-09	0.0173
	n										124	124	124	124	124	124	124
Urea	R											0.347	0.161	0.149	0.165	0.119	0.103
(μmol L^{-1})	p											0.0000796	0.0744	0.0991	0.0667	0.188	0.256
	n											124	124	124	124	124	124
DFAA N	R												0.107	0.117	0.128	0.0934	-0.12
(μmol L^{-1})	p												0.239	0.194	0.138	0.302	0.185
	n												124	124	124	124	124
DIN	R													0.166	0.291	0.624	0.31
(μmol L^{-1})	p													0.0654	0.00105	9.19E-15	0.000454
	n													124	124	124	124
DON	R														0.992	0.155	0.116
(μmol L^{-1})	p														8.20E-111	0.0866	0.199
	n														124	124	124
TDN	R															0.231	0.153
(μmol L^{-1})	p															0.00987	0.0901
	n															124	124
PO$_4^{3-}$	R																0.0894
(μmol L^{-1})	p																0.323
	n																124
SiO$_4^+$	R																
(μmol L^{-1})	p																
	n																

Appendix table B.7. Continued.

HCO_3^- daily (μmol L^{-1} d^{-1})	HCO_3^- Chl *a* normalized (μmol μg chl^{-1} d^{-1})	NH_4^+ volumetric (μmol L^{-1} h^{-1})	NO_2^- volumetric (μmol L^{-1} h^{-1})	NO_3^- volumetric (μmol L^{-1} h^{-1})	Urea volumetric (μmol L^{-1} h^{-1})	DFAA N volumetric (μmol L^{-1} h^{-1})	TN volumetric (μmol L^{-1} h^{-1})	NH_4^+ Chl *a* normalized (μmol μg chl^{-1} h^{-1})	NO_2^- Chl a normalized (μmol μg chl^{-1} h^{-1})	NO_3^- Chl a normalized (μmol μg chl^{-1} h^{-1})	Urea Chl a normalized (μmol μg chl^{-1} h^{-1})	DFAA N Chl a normalized (μmol μg chl^{-1} h^{-1})	TN Chl a normalized (μmol μg chl^{-1} h^{-1})
0.346	0.431	0.316	0.0944	0.249	0.247	-0.089	0.295	0.293	0.124	0.317	0.299	0.164	0.313
0.00097	0.0000275	0.00268	0.382	0.0193	0.0205	0.409	0.00534	0.00567	0.25	0.00266	0.00459	0.127	0.00281
88	88	88	88	88	88	88	88	88	88	88	88	88	88
-0.233	-0.115	-0.338	0.0614	-0.254	-0.0627	-0.176	-0.276	-0.32	-0.268	-0.385	-0.175	-0.231	-0.339
0.0287	0.284	0.00127	0.57	0.0168	0.562	0.1	0.00913	0.00238	0.0117	0.00021	0.102	0.0306	0.00121
88	88	88	88	88	88	88	88	88	88	88	88	88	88
-0.0569	-0.319	-0.0122	-0.0888	-0.0645	-0.17	0.133	-0.0558	-0.119	-0.0321	-0.111	-0.165	-0.127	-0.135
0.541	0.000439	0.896	0.339	0.488	0.0657	0.152	0.548	0.201	0.73	0.231	0.0739	0.171	0.145
118	118	118	118	118	118	118	118	118	118	118	118	118	118
0.00992	-0.189	0.0887	-0.0567	0.0417	-0.0847	0.0349	0.035	0.0186	0.0767	0.0322	-0.0481	-0.0432	0.0136
0.915	0.0409	0.342	0.544	0.655	0.364	0.708	0.708	0.842	0.411	0.73	0.606	0.644	0.884
117	117	117	117	117	117	117	117	117	117	117	117	117	117
0.043	-0.0753	0.178	-0.0571	0.078	-0.0343	0.0766	0.112	0.164	0.176	0.158	0.0427	0.069	0.161
0.645	0.42	0.0545	0.541	0.403	0.713	0.412	0.228	0.0769	0.0576	0.0898	0.647	0.46	0.0823
117	117	117	117	117	117	117	117	117	117	117	117	117	117
-0.244	-0.0635	-0.176	-0.00412	-0.232	-0.101	-0.249	-0.212	0.0353	0.219	-0.0702	-0.0187	0.0299	0.0292
0.0563	0.624	0.17	0.975	0.0691	0.435	0.0505	0.0981	0.785	0.0865	0.588	0.885	0.817	0.822
62	62	62	62	62	62	62	62	62	62	62	62	62	62
-0.203	0.00313	-0.197	-0.228	-0.267	-0.0692	-0.205	-0.236	-0.0133	-0.131	-0.105	0.0104	-0.00826	-0.0342
0.113	0.981	0.125	0.0745	0.0356	0.593	0.109	0.0647	0.918	0.312	0.415	0.936	0.949	0.792
62	62	62	62	62	62	62	62	62	62	62	62	62	62
0.304	0.113	0.213	0.122	0.193	0.00376	0.117	0.208	0.124	-0.0523	0.126	0.0588	0.078	0.11
0.000827	0.223	0.0203	0.189	0.0362	0.968	0.208	0.0235	0.182	0.574	0.173	0.527	0.401	0.234
118	118	118	118	118	118	118	118	118	118	118	118	118	118
-0.163	-0.258	-0.23	0.246	-0.157	-0.115	-0.163	-0.164	-0.207	-0.0172	-0.202	-0.156	-0.212	-0.209
0.0771	0.00474	0.0123	0.00722	0.0886	0.216	0.078	0.0752	0.0243	0.854	0.028	0.0926	0.0212	0.0229
118	118	118	118	118	118	118	118	118	118	118	118	118	118
-0.0247	-0.0839	-0.136	-0.109	-0.101	-0.0359	-0.161	-0.155	-0.109	-0.194	-0.118	-0.0829	-0.207	-0.136
0.79	0.367	0.143	0.239	0.276	0.7	0.0825	0.0942	0.241	0.0357	0.205	0.372	0.0242	0.141
118	118	118	118	118	118	118	118	118	118	118	118	118	118
-0.0333	0.0645	-0.0162	-0.0207	0.00522	0.0291	0.113	0.0103	-0.0601	-0.111	-0.0314	-0.0135	0.0508	-0.0546
0.72	0.488	0.862	0.824	0.955	0.754	0.222	0.912	0.518	0.233	0.736	0.885	0.585	0.557
118	118	118	118	118	118	118	118	118	118	118	118	118	118
-0.0113	0.0095	0.213	0.0145	0.114	-0.0374	0.469	0.213	-0.0668	-0.0537	0.0364	-0.0838	0.116	-0.0514
0.904	0.919	0.0205	0.876	0.218	0.687	8.72E-08	0.0204	0.472	0.549	0.696	0.367	0.209	0.58
118	118	118	118	118	118	118	118	118	118	118	118	118	118
0.0801	-0.053	-0.0458	0.00399	-0.0183	-0.0417	-0.093	-0.0522	-0.0585	-0.163	-0.0631	-0.0589	-0.149	-0.0842
0.388	0.569	0.622	0.949	0.844	0.654	0.317	0.575	0.529	0.0782	0.497	0.527	0.107	0.365
118	118	118	118	118	118	118	118	118	118	118	118	118	118
0.252	0.174	0.2	-0.0563	0.236	-0.0356	0.00455	0.145	0.282	0.171	0.363	0.149	0.198	0.296
0.00581	0.0597	0.0302	0.544	0.0101	0.702	0.961	0.116	0.00201	0.0634	0.0000523	0.106	0.032	0.00114
118	118	118	118	118	118	118	118	118	118	118	118	118	118
0.256	0.162	0.188	-0.0539	0.227	-0.04	-0.00772	0.134	0.266	0.145	0.345	0.137	0.172	0.276
0.00521	0.0798	0.0417	0.562	0.0136	0.667	0.934	0.147	0.00364	0.117	0.000133	0.138	0.062	0.00245
118	118	118	118	118	118	118	118	118	118	118	118	118	118
0.0518	-0.212	-0.0652	-0.136	0.0197	-0.198	-0.128	-0.126	-0.175	-0.27	-0.156	-0.237	-0.238	-0.223
0.577	0.0212	0.483	0.141	0.832	0.0318	0.168	0.175	0.0577	0.0031	0.0923	0.00987	0.00954	0.0154
118	118	118	118	118	118	118	118	118	118	118	118	118	118
-0.0577	-0.126	-0.145	-0.0317	-0.0457	-0.0894	-0.199	-0.151	-0.163	-0.0877	-0.104	-0.0832	-0.182	-0.158
0.535	0.176	0.117	0.733	0.623	0.335	0.0307	0.104	0.078	0.345	0.261	0.37	0.0486	0.0879
118	118	118	118	118	118	118	118	118	118	118	118	118	118
	0.567	0.675	0.0653	0.761	0.501	0.271	0.714	0.286	0.0339	0.451	0.435	0.361	0.359
	2.21E-11	4.86E-17	0.482	1.67E-23	7.63E-09	0.00297	1.16E-19	0.00167	0.716	0.000000293	0.000000834	0.0000605	0.0000654
	118	118	118	118	118	118	118	118	118	118	118	118	118
		0.368	0.0166	0.378	0.638	0.215	0.468	0.342	0.135	0.468	0.731	0.577	0.474
		0.0000409	0.858	0.0000246	7.96E-15	0.0196	8.98E-08	0.000151	0.144	9.31E-08	6.07E-21	8.33E-12	5.97E-08
		118	118	118	118	118	118	118	118	118	118	118	118
			0.14	0.716	0.362	0.4	0.901	0.445	0.148	0.406	0.212	0.373	0.426
			0.129	8.52E-20	0.0000576	0.00000738	6.68E-44	0.000000455	0.111	0.00000519	0.021	0.00036	0.0000015
			118	118	118	118	118	118	118	118	118	118	118
				0.182	0.155	0.182	0.391	-0.0209	0.398	0.00682	0.0101	0.104	0.0357
				0.0489	0.0933	0.0491	0.0000118	0.822	0.000008	0.942	0.913	0.263	0.701
				118	118	118	118	118	118	118	118	118	118
					0.444	0.396	0.816	0.241	0.122	0.533	0.28	0.404	0.329
					0.000000484	0.00000927	2.42E-29	0.00749	0.188	5.05E-10	0.00213	0.0000057	0.000281
					118	118	118	118	118	118	118	118	118
						0.412	0.616	0.0938	0.0917	0.263	0.717	0.487	0.267
						0.00000347	1.19E-13	0.312	0.324	0.00407	7.07E-20	0.000000022	0.00343
						118	118	118	118	118	118	118	118
							0.592	-0.0204	0.00867	0.0859	0.148	0.399	0.0644
							1.64E-12	0.827	0.926	0.355	0.109	7.81E-13	0.489
							118	118	118	118	118	118	118
								0.325	0.217	0.418	0.363	0.489	0.393
								0.000329	0.0182	0.00000249	0.0000533	1.91E-08	0.0000105
								118	118	118	118	118	118
									0.624	0.838	0.496	0.47	0.964
									4.56E-14	2.59E-32	0.000000011	7.91E-08	2.36E-68
									118	118	118	118	118
										0.576	0.445	0.473	0.706
										9.11E-12	0.00000043	6.23E-08	4.43E-19
										118	118	118	118
											0.615	0.582	0.905
											1.23E-13	4.56E-12	7.98E-45
											118	118	118
												0.643	0.68
												4.23E-15	2.38E-17
												118	118
													0.621
													6.51E-14
													118

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